Coefficient of Friction Effects of Polymers, Silicone Oil, and Mini-Rollers in Cable Pulling

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Abstract–Cable pulling friction coefficients are determined for several control pulling compounds, and those same compounds supplemented with a silicone polymer (dimethyl polysiloxane) and/or mini-rollers (small plastic spheres). The data are developed for fiber optic cable in polyethylene duct and electrical cable in PVC duct by pulling cables through a multi-bend conduit system and calculating the effective coefficient of friction. The data should provide a quantitative means to evaluate the effect of cable pulling lubricants supplemented with these components.

I. INTRODUCTION

A major concern when installing cables in conduit is minimizing the tension on the cables as they are pulled. Recent research has focused on how much pulling tension and sidewall pressure cables can safely tolerate, as in [1], as well as how such tension can be accurately predicted, as in [1], [2], [4], [5], and [6].

A theoretical basis for predicting cable pulling tension has existed for over four decades. This theory was described and the cable pulling equations developed in the well-known paper by Riffenberg, as in [3]. A key variable in these equations is the friction coefficient, which is a measure of the frictional forces between the cable jacket and conduit wall. The measurement and development of meaningful friction coefficients for use in the pulling equations has also been the subject of much research, as in [1], [2], [4], [5], and [6].

The research cited develops a number of variables which affect the coefficient of friction. Key among these variables are:

- conduit type
- cable jacket type
- lubricant presence and type
- temperature
- normal or conduit-directed pressure on the cable
- number of cables
- conduit fill

One of the more significant factors affecting coefficient of friction is the presence of lubricant and the type of lubricant. The discovery that not all lubricants were the same accelerated the development of improved pulling lubricants, with lower friction coefficients that produce lower pulling tensions.

Over the past 15 years, the clay slurry lubricants common in power cable installation have been replaced by lower friction, water-soluble organic polymer lubes, based on polyethers, polyalcohols, polyamides, and/or neutralized polyacids. These water-soluble polymers, especially those of higher molecular weight, slipperify water when dissolved at low concentrations. Some of the polymer materials are also oily and lubricious in their own right, and continue to lubricate even after their water carrier has evaporated.

Recently, silicone oil polymers (dimethyl polysiloxane), which are not water soluble, have been emulsified in water systems and used in cable pulling lubricants, usually in combination with other polymer systems.

Another unique approach to lubrication has been the use of mini-rollers (small spheres) in lubricants. These rollers are intended to function as bearings or wheels which actually roll the cable along as it is pulled.

It has been difficult to evaluate the benefits of these lubrication approaches. Field research is not practical, since a series of multiple lubricants must be specially

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compounded and tested with adequate controls to quantify the effectiveness of any particular ingredient or approach.

In this research, lubricant controls were developed which were supplemented with both silicone and mini-rollers. The laboratory testing included two types of friction measurement, both of which measured tension on actual cable pulls and calculated the effective coefficient of friction.

The results and conclusions from the research should help cable installers and planners determine the potential of various lubricant technologies. The data can be used for a cost/benefit analysis of lubricant ingredients.

II. BODY

A. Test Conditions

Two different test conditions were used to develop friction data. Both involved pulling cable and calculating the "effective coefficient of friction" from measured input (back) tension and pulling tension. The first test set-up (Condition 1) utilized fiber optic cable and HDPE innerduct. Condition 2 utilized electrical cable in hard-sided PVC duct.

Both conditions used multi-bend conduits with an adjustable back tension and a measured pulling tension. The theory and operation of such a multi-bend test is described in [6].

In both conditions, coefficients of friction were found to vary with back tensions. In the multi-bend pulling, the decrease in friction coefficient with increasing back tension is both significant and consistent. This variation of coefficient of friction with normal pressure (sidewall pressure) has been observed and described in a number of research papers, as in [1], [4], and [6].

Additional details on the measurement techniques are:

Condition 1: Continuous HDPE duct with 6 each 90° bends. One-inch smoothwall duct was used with no pretreatments. Cable was fiber optic with LDPE jacket. Conduit fill was 45%. Back tension was varied from 1 lb. to 12 lbs. Maximum load cell capacity (pulling tension) was 100 lbs.

Condition 2: Hardsided PVC schedule 40 duct with 6 each 90° bends. Cable was 600V with XLPE jacket. Back tension was varied from 10 to 200 lbs. Conduit fill was 47%. Maximum pulling capacity was 1200 lbs.

B. Calculations

The coefficient of friction was calculated from

$$COF = \frac{2}{Wn\pi} \ln\left(\frac{T_{out}}{T_{in}}\right) \qquad (1)$$

Where: COF = effective Coefficient of Friction
n = number of 90° bends
W = occupancy of weight correction factor
T_{out} = measured pulling tension
T_{in} = measured incoming tension

C. Basic Lubricant Compounds

Two basic lubricant types were compounded for these tests. They represented two of the common chemical approaches in commercial pulling lubricants today. These compounds were:

Lubricant A: a water-based polyacrylamide/oleate lubricant
Lubricant B: a water-based polyalkane glycol lubricant

D. Supplements

To determine the effect of the silicone oil supplement (coded as "SO" in data) and the mini-rollers (coded "MR" in data), they were added to Lubricants A and B in a full factorial design for Condition 2, and a partial factorial in Condition 1. The lubricant was applied to the cable, pulling tensions were measured, and friction coefficients were calculated and plotted against incoming tension.

These data are presented below with comment. The lube type, supplement(s), if any, and test condition are detailed on the graphs.

Plain Lubricants

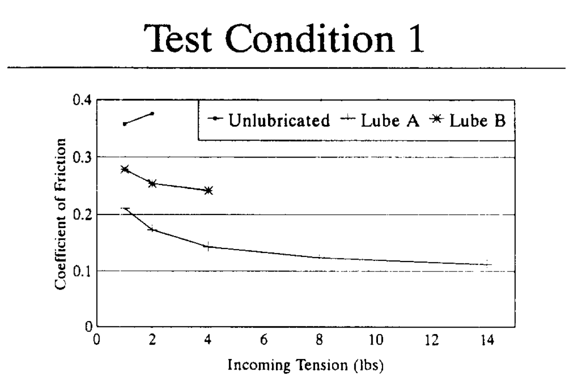


Figure 1. Effective Coefficient of Friction Using Plain Lubricants

Test Condition 2

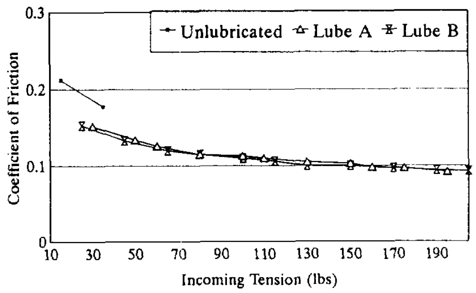


Figure 2. Effective Coefficient of Friction using Plain Lubricants

The data (Figure 1) show coefficients of friction from .1 to .2 for the Lube A and the fiber optic cable, .25 to .3 for Lube B, and .35 to .40 for unlubricated.

At the higher incoming tensions and sidewall pressures of Condition 2 (Figure 2), the friction coefficients of "A" and "B" are very similar and run from .15 to slightly under .1. For some reason, the unlubricated friction coefficient of .18 to .21 is lower than previous tests of similar jackets on the same test device. Regardless of this low, unlubricated coefficient of friction, the jacket was abraded and damaged at back tensions above 50 lbs., so additional data points could not be generated.

Figure 3 shows the damage to the unlubricated cable from pulling.

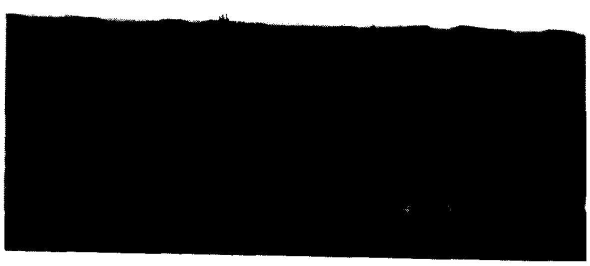


Figure 3. Damage to the Unlubricated Cable From Pulling Through Multiple Bends

Lubricants with Silicone Oil Supplement

Test Condition 1

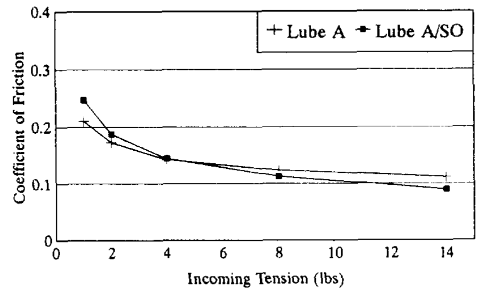


Figure 4. Effective Coefficient of Friction Using Lubricant A w/wo Silicone

Test Condition 1

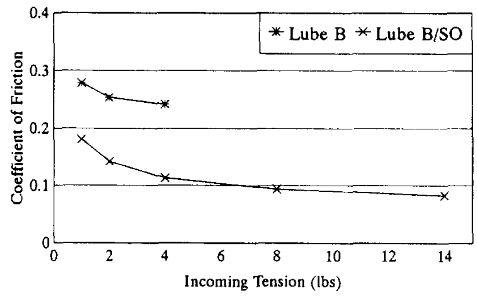


Figure 5. Effective Coefficient of Friction Using Lubricant B w/wo Silicone

Test Condition 2

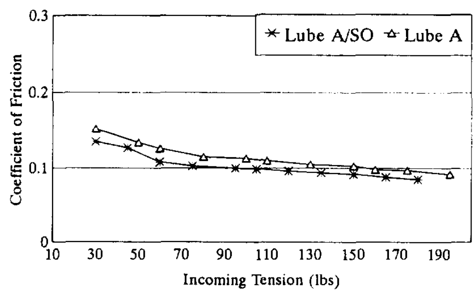


Figure 6. Effective Coefficient of Friction using Lubricant A w/wo Silicone

Test Condition 2

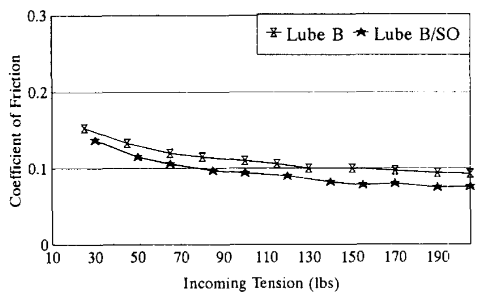


Figure 7. Effective Coefficient of Friction using Lubricant B w/wo Silicone

Even with the different test conditions, lubricants, cable types, etc., the results in Figures 4 through 7 show a consistent enhancement of lubricity with the silicone oil supplement.

The magnitude of the improvement varies, and averages around 10% for the electrical cable pulls. While the improvement in friction coefficient from the silicone is relatively small, it is consistent, even through the high sidewall pressures at the higher input tensions of Condition 2 (800+ lbs./ft.).

Lubricants with Mini-Roller Supplement (Plastic Spheres)

Test Condition 1

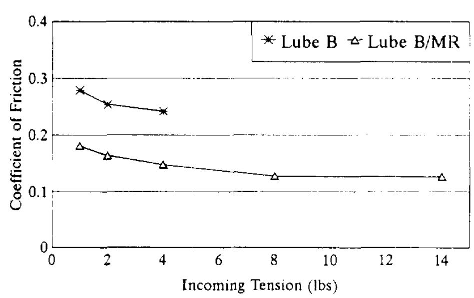


Figure 8. Effective Coefficient of Friction Using Lubricant B w/wo Roller Spheres

Test Condition 2

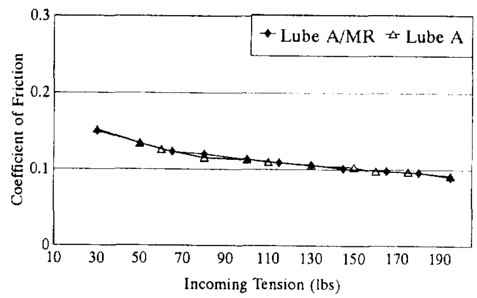


Figure 9. Effective Coefficient of Friction using Lubricant A w/wo Roller Spheres

Test Condition 2

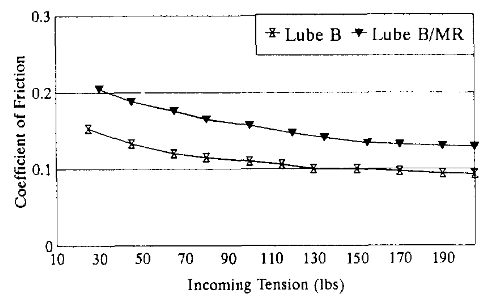


Figure 10. Effective Coefficient of Friction using Lubricant B w/wo Roller Spheres

These results show some variation. In Figure 8 with the fiber optic cable, the rollers significantly improve the Lubricant B. However, as noted previously, Lubricant B was not very efficient for this type of pulling, and the improvement is only to the .18 to .14 range.

For the higher sidewall pressure Condition 2 (Figures 9 and 10), the mini-rollers do not reduce friction coefficient, and significantly increase it with the Lubricant B.

It was also noted that the mini-rollers pressed into the jacket during the pulling in all of the tests. This left "craters" in the jacket with depth equivalent to the ball's diameter. Many of the mini-rollers remained imbedded in the cable after it was removed from the conduit. Figure 11 shows this physical damage.

Figure 11. Craters and Pock Marks Left in the Jacket By the Mini-Rollers

Lubricants with Both the Silicone Oil <u>and</u> Mini-Roller Supplements

Test Condition 1

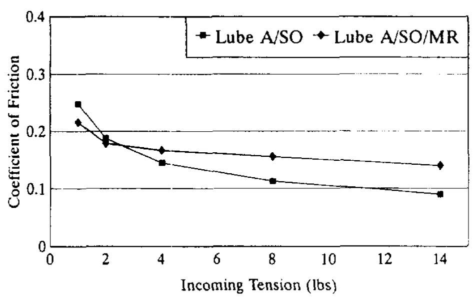


Figure 12. Effective Coefficient of Friction Using Lubricant A with Silicone and w/wo Roller Spheres

Test Condition 1

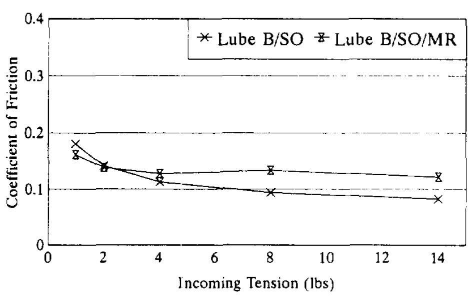


Figure 13. Effective Coefficient of Friction Using Lubricant B with Silicone and w/wo Roller Spheres

Test Condition 2

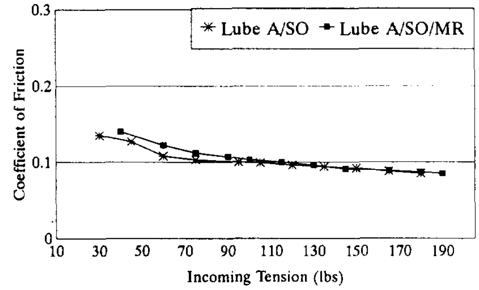


Figure 14. Effective Coefficient of Friction using Lubricant A with Silicone and w/wo Roller Spheres

Test Condition 2

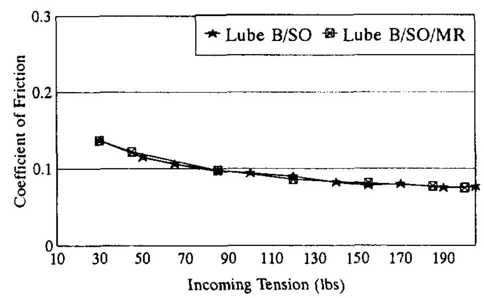


Figure 15. Effective Coefficient of Friction using Lubricant B with Silicone and w/wo Roller Spheres

Again, these results are consistent. The addition of the rollers does not reduce, and often increases, the friction of the silicone-supplemented lubes. Remember that the silicone-supplemented lubricants <u>without rollers</u> are highly efficient, showing friction coefficients for electrical pulling from .15 to .06.

III. CONCLUSIONS

The research described in this paper is limited to only a few jackets and conduits. Since we know that friction coefficient varies with both jacket and conduit, we do not know how universal any conclusions might be. However, there are some very interesting and useful conclusions based on the cables, conduits, and lubes tested.

The high performance polymer lubricants show friction coefficients in the .10 to .20 range. This is in agreement with other studies in both the lab and the field, as in [2], [4}, and [6]. The silicone oil supplement further lowers this coefficient of friction. With this improvement in the 10% range, it means 10% lower tensions on straight pulls, or 10% longer pulls with the same tension.

However, when the pulls include multiple bends, the coefficient of friction is calculated exponentially, and tension is reduced much more than 10%. Silicone oils are relatively expensive; and even when present only as a low percentage in a lubricant, they can have a significant cost effect. End-users should be able to determine if the increased costs would be justified, based on the specifics of the pull(s) planned.

The inclusion of the mini-rollers in the lube does not offer any measurable benefit. With one exception, the rollers either increased tension or did not change it. There was no synergy of the rollers and the silicone. Additionally, the rollers abrade and mar the cable jacket. The extent of damage is limited by the rollers' size.

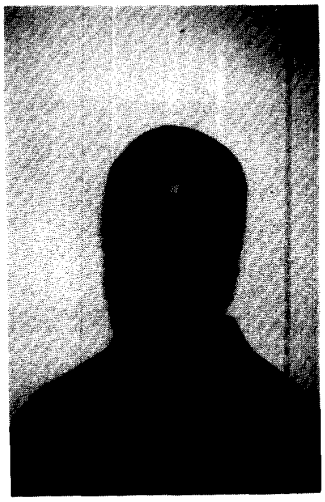
In the future, we hope to further investigate these lubricant ingredients by broadening the evaluation to different cable jackets and conduits. If the results are consistent, silicone-supplemented lubricants could result in improved pulling and lower tension in critical cable pulls.

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.



Dale P. Solheid is a chemical engineering student at the University of Minnesota in Minneapolis.

Mr. Solheid works as an intern at American Polywater Corporation. His work includes development of process procedures as well as research into the friction character of lubricants.

V. REFERENCES

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