ANALYSIS AND MEASURMENT OF FRICTION IN HIGH SPEED AIR BLOWING INSTALLATION OF FIBER OPTIC CABLE

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ABSTRACT

A method was developed for measuring friction properties in high speed air blowing of fiber optic cable. Significant differences were observed between unlubricated and lubricated systems, as well as between various types of lubricants. The flexibility of the cable was determined to be another significant factor in blowing force. The analysis of the data did not correlate well using existing models. The experimental methods and data should help in the optimization of high speed air blowing fiber optic installation.

INTRODUCTION

Several new methods of installing fiber optic cable in continuous conduit use high speed air flow to "push" the cable, rather than the traditional threaded line to pull it. Air blowing installation methods offer special advantages in conduits with many bends, such as the winding caused by reel memory when the innerduct is placed in open trenches.

In cable pulling through a bend, force anlysis develops equations of the form [Ref 1]:

$$T_{out} = T_{in} \times e^{\theta\mu} \tag{1}$$

Where:
T_{out} = tension out of the bend
T_{in} = tension into the bend
θ = angle of the bend
μ = coefficient of friction

Even with the low friction coefficients measured with todays pulling lubricants (0.15 and lower), a 50 lb cable tension increases to 600 lbs going through 950 degrees of bend. As an extreme example, this is only 35 feet of duct length if the duct is on a 4 foot diameter reel.

It has been hypothesized that high speed air blowing results in a "localized" force completely along the cable (via rushing air), and this eliminates the exponential character of going through bends [Ref 2]. In fact, the model indicates the cable should behave as if the conduit was straight, regardless of its true configuration.

In the research presented in this paper, high speed air blowing refers to the installation method with a wide-open conduit which allows high speed laminar air flow. This results in a pressure differential along the length of the conduit. In a variation of high speed air blowing, a piston or missle is placed in front of the cable, and the air pressure pushes on the piston which at least partially "pulls" the cable. The analysis of piston blown cable is presumably a mixture of the physics of pulling and of high speed air flow pushing.

FRICTION FACTOR

Field experience indicates that a number of factors can influence the maximum length that cable can be blown. Three significant factors are shown to be [Ref3]:

1) The relative size of cable to conduit
2) The "stiffness" or force required to bend the cable
3) The friction character of the jacket on the conduit

The purpose of our research was to study the friction factor in air blowing. Field experience with air blowing has shown that friction reduction can be quite important. It is known that cable can be blown several times farther in lubricated duct than in plain duct. However, efforts to lubricate as part of the air blowing process have been inconsistent, and no known efforts have been made to optimize or measure frictional differences in the blowing environment. The lubrication that is done in both Europe and the US has used either light paraffin oils or silicone oil emulsions.

Conventional fiber optic <u>pulling</u> lubricants have not worked well in the blowing process. References [4 and 5] show that good pulling lubricants produce their lowest coefficients of friction under high normal pressures, such as a cable being pulled around (and "into") a bend. In pulling, such bends are the primary tension producers, so these low friction coefficients make the lubricants quite effective. However, blowing never puts the cable in a high normal force mode. In fact, the viscosity and cling character of pulling lubricants, which keeps them on cable over long distances, probably interferes with the cable movement in the low normal force situation in air blowing.

However, we can still learn about cable/conduit friction from some of the studies [Ref 4 and 6] that have been done on cable pulling. This work shows that coefficient tof friction is dependent on a number of key variables including:

1) Cable jacket material
2) Conduit material
3) Temperature
4) Lubricant type and presence
5) Normal force between cable and conduit

While controlled studies on the variables affecting friction have not been done for air blowing, already there is a consensus that conduit, temperature, and lubricant are significant factors, presumably because they affect the coefficient of friction.

We can follow the differential pressure model by Griffioen in [2] to predict the effect of friction differences on air blowing. This model is based on fluid flow dynamics and assumes that air behaves as an incompressible fluid. The model calculates the force per length on the cable from the air flow as:

$$F/l = dp/dz \times \pi \times r_{cab} \times r_{con} \qquad (2)$$

Where:
F/l = force per unit of length
dp/dz = the pressure gradient
r_{cab} = cable outer radius
r_{con} = conduit interior radius

Whether the pressure gradient is [Ref 2]:

$$-dp/dz = (p_0^2 - p_1^2)/2lp(z) \qquad (3)$$

Where:
p_0 and p_1 are entry and exit pressures
$p(z)$ is local pressure at z distance from entry

or is a constant [Ref 7]:

$$-dp/dz = (p_0 - p_1)/l \qquad (4)$$

makes no difference if the runs are long enough that the final pressure (p_1) is at a minimum (1 Atm). Under these boundary conditions, (2) and (3) or (4) show the total force on the cable does not change with increasing run length, as long as the entry pressure is the same.

We know that the cable will accelerate (move) when the force from the air flow is greater than the frictional resistance force. This frictional force is given simply by:

$$F_{fric} = \mu \times W \qquad (5)$$

Where:
μ = coefficient of friction
W = weight of cable in conduit

Since the weight of cable in the conduit is proportional to the conduit length, and the blowing force does not vary as length, we see from equation 5 that the maximum blowing length must vary inversely to changes in the coefficient of friction. Simply put, cut the coefficient of friction in half, blow twice as far.

EXPERIMENTAL METHOD

To quantify a friction effect, a full–flow type blowing machine was hooked up to a 1.25 inch smoothwall innerduct. A 0.46″ fiber optic cable was hand pushed/blown through the entire length of conduit. The mechanical pushing unit was deactivated for the test so **the only forces acting on the cable were the pushing force from the air and the frictional force resisting movement.** A 365 cfm compressor was regulated to produce varying pressures at the head of the blowing unit. Different conduit lengths and configurations were tested. As the air flow and pressure were varied, the forces required to "push" (defined as positive) or to "hold-back" the cable (defined as negative) were measured with a load cell.

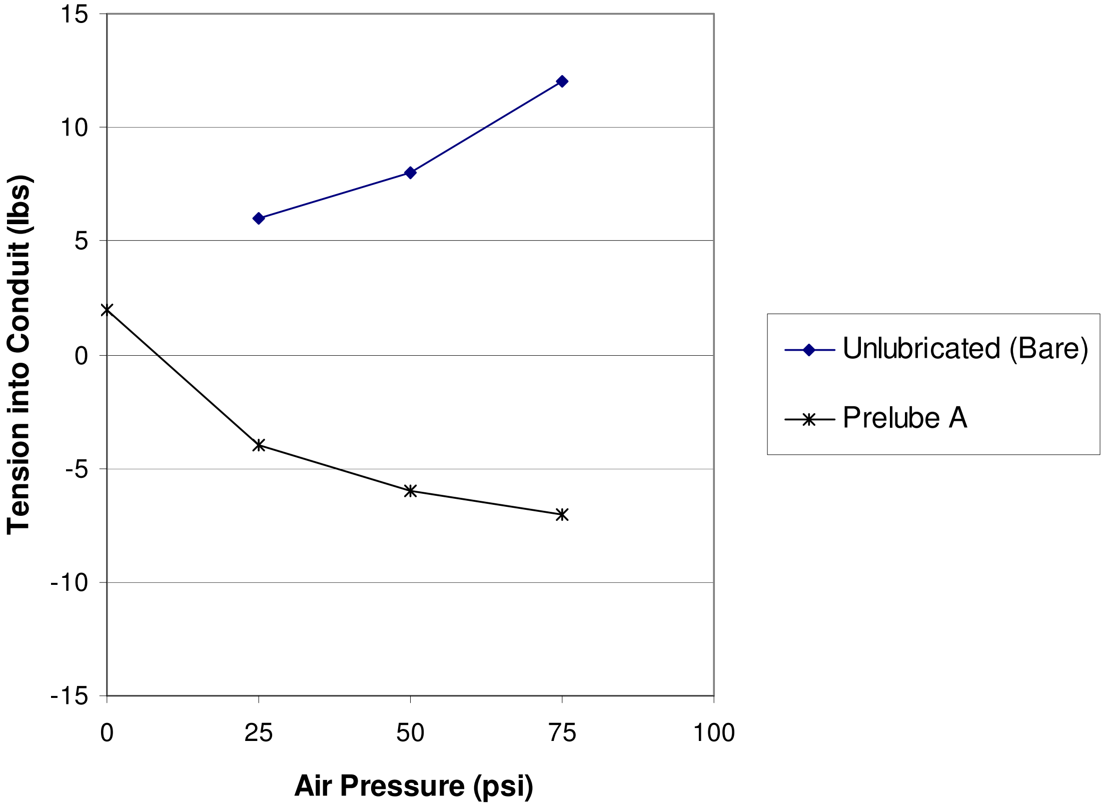
The actual experiments were conducted over a month period in early Fall 1994. The method was designed to use relatively short runs of cable and conduit, because both were scrapped after they were contaminated with any lubricant. Previous experience indicated that it was not realistic to clean and use them again. However, configurations of the same length did use the same duct and cable. It was simply left threaded and rearranged.

The force data represent between 5 and 10 measurements at each point. The data represent "dynamic" friction. In other words, the cable was moving (slowly) when the force was measured. For positive forces (pushing required), this was easy to do. However, for negative forces (when the cable was pulling), the measurer had to resist the temptation to pull back on the slowly advancing load cell, inflating the reading.

Mechanically compressed air used in this volume is both "wet" and "hot". The air often appeared to be "foggy" as it blew out of the end of the duct. This initial "foggy" appearance seemed to disappear after a few minutes of blowing in most cases. This undoubtedly depended on the relative humidity of the air that was compressed. The air was hot enough that the first few feet of duct were too hot to hold onto. While not measured, the temperature was presumably about 130° F. There was no way to control these variables over a 30 day period, and whatever variation they introduced is in the data. The system was allowed to blow for awhile to reach an equilibrium before measurements were taken to minimize these potential effects.

We know that the viscous air forces exerted on the cable depend on duct size and type, cable size and type, as well as cable stiffness. These parameters were not varied (with one noted exception). The intent was to evaluate the experimental method and its results without analyzing variables other than lubricant and configuration.

The procedure can be better understood by looking at the actual experimental data in graph #1. This graph compares blowing cable thru a plain duct versus through a duct lubricated with prelubricant A. The configuration was 300 feet with 720 degrees of bend (laid out in large circles on top of the ground).



Graph #1. Force Measurements Blowing Through
300 ft With 720 deg of Bend

We see data points at 25, 50 and 75 psi. With our 365 cfm compressor in this 300 feet of duct, 75 psi was the highest back pressure produced with full air flow. We also see a data point at 0 psi. 0 (zero) psi means no air, so the point is simply the force required to push the cable. No data point at zero indicates a force above 15 lbs, since at 15 lbs this cable would begin to buckle, fold on itself, and could not be pushed. This was the case for the non-lubricated system in Graph #1, so there is no data point at 0 psi.

Remembering the conventions, the unlubricated cable took between 6 and 12 lbs of pushing force. It would not advance on its own. Surprisingly, it took more force at the high air flows than the low.

The cable in the prelubricated conduit produced negative forces at all of the air flows tested. This means that it was pulling on the load cell, and would advance if it wasn’t held back. While 10 lbs of force does not seem like much, a cable pulling with this force would accelerate to speeds well over 500 ft/min if we let it go.

We can attempt to use this data to determine the friction coefficient from the models that have been discussed.

At the first level, we can look at the forces measured with “no air”. The cable we used weighed 78 lbs/M ft, so the weight of cable in 300 feet of conduit was 23.4 lbs. It took an average of 2.2. lbs to “push” this cable in the lubricated conduit, yielding a coefficient of friction of 0.09 (Equation 5). While low, this coefficient is consistent in magnitude with those that have been measured for pulling lubricants. On the other hand, the coefficient of friction for the unlubricated cable is over 0.6, again, consistent with previous work.

However, when we use the model [Ref 2] from incompressible liquid flow theory, there is no good agreement. We see from Graph #1 that it takes entry air pressure of around 10 psi to overcome the cable’s frictional resistance to movement in the prelubricated duct. This is where the Prelube A line crosses from positive to negative. Following equation 2 with the 0.46″ OD cable being blown, we calculate a total force on the cable from the air of 18.2 lbs at the 10 psi level. With 23.4 lbs of cable this gives a coefficient of friction of 0.78. This is too high to be realistic. Without belaboring the calculations here, the agreement does not improve for longer lengths of blow or for higher pressure and a non-balanced force approach. The model is simply not adequate to analyze this data.

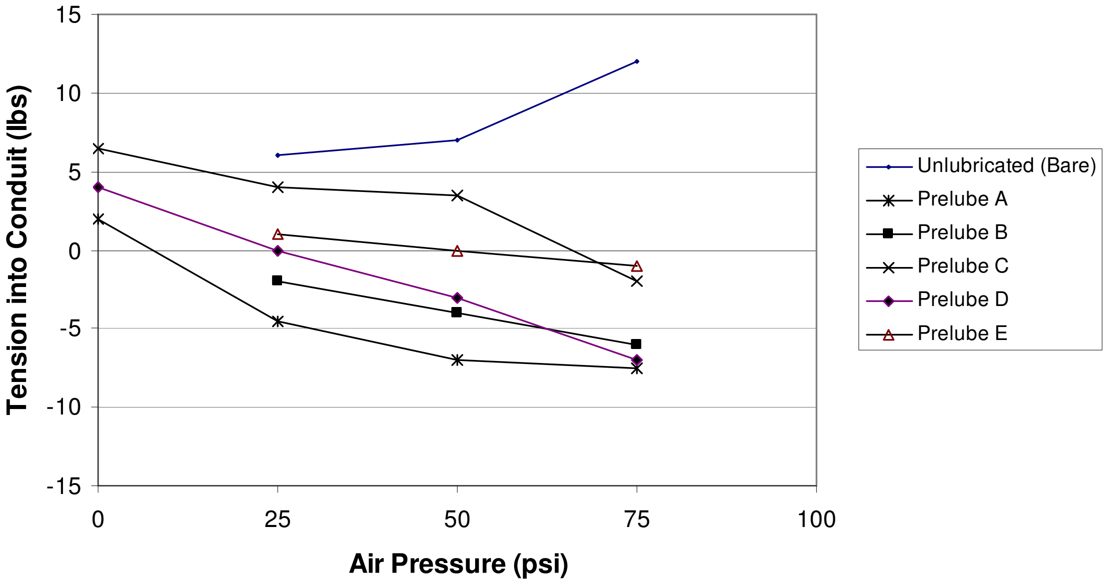
The upward slope of the unlubricated cable in Graph #1 is also not consistent with the fluid flow model. The model does not predict greater forces required to move cable with increased air volume and head pressure, at the higher coefficients of friction. However, we can still learn quantitatively from the data, and perhaps refine or redefine the model based on the measured results.

This method described and shown in Graph #1 was used to study a number of variables, including

1) Lubricant types and varieties
2) Conduit configurations and lengths

LUBRICANT TYPES

Graph #2 adds a number of lubricants to the data from #1. The same amount of each lubricant was applied to each new conduit. This amount was chosen based on laboratory studies showing it to be optimal. A separate study not described here in detail established that upward variations from this optimal quantity had no significant effect on the results. All the lubricants were applied in the same way, by blowing a tight fitting sponge through the conduit to spread the lubricant. A number of lubricants were specially formulated for this study, and included proprietary variations in functionality and physical properties. Of interest, a paraffin lubricant typical of those used in Europe was included. The paraffin is Prelube E.

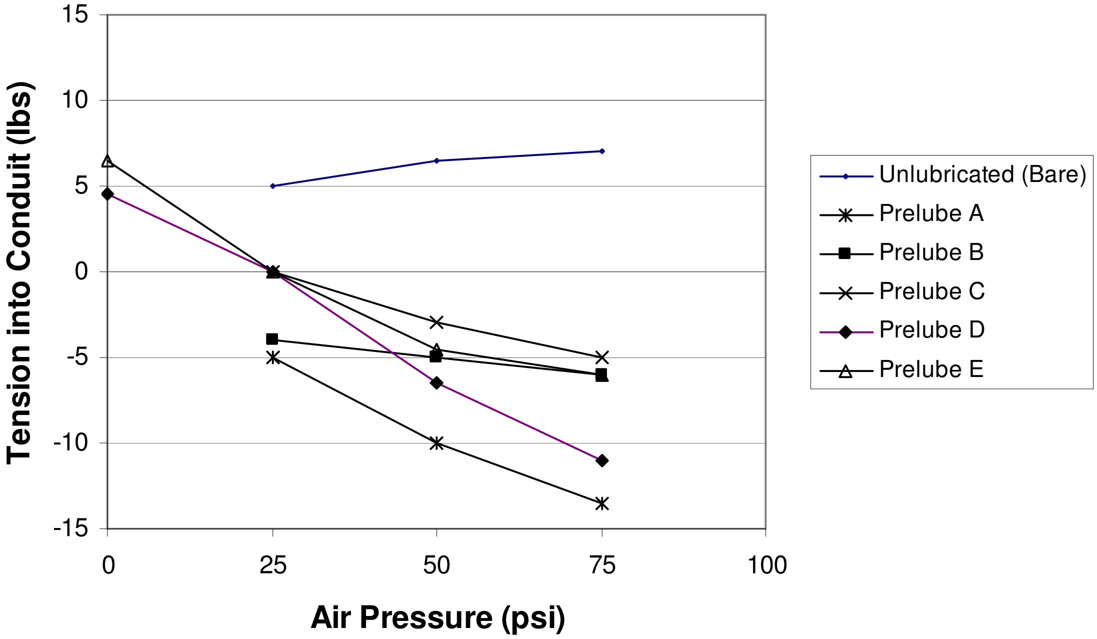


Graph #2. Force Measurements Blowing Through 300 ft With 720 deg of Bend

While all of the lubricants lower the force compared to the unlubricated control, there are significant differences in how they perform. Some lubricants are more effective in the blowing environment than others.

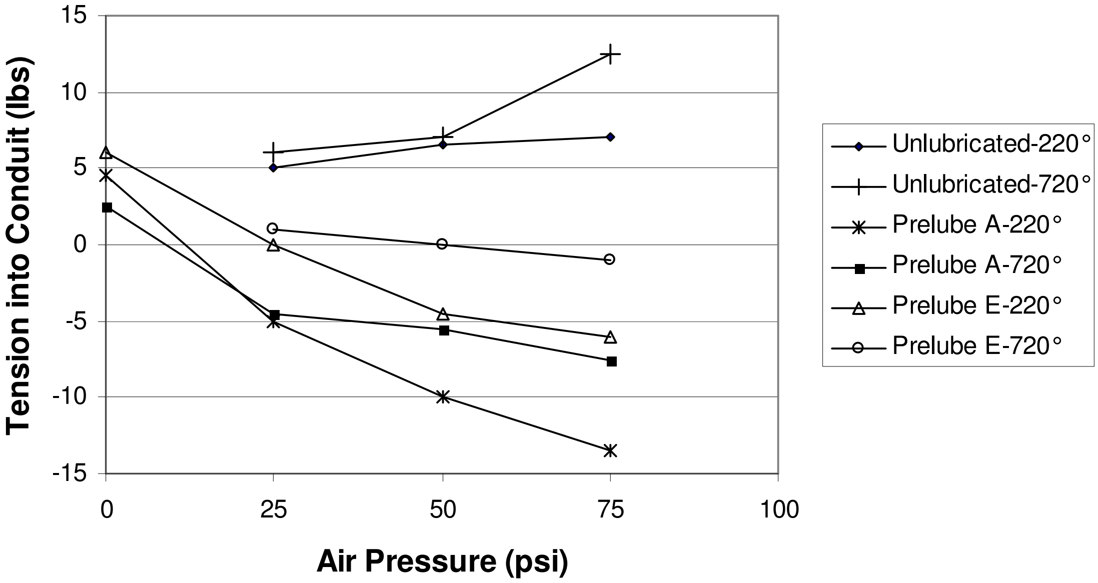
CONFIGURATION CHANGE

Graph #3 shows data from a second configuration of the same 300 feet of duct. This configuration started with a 200 degree U-turn and then went essentially straight. The five lubricants and unlubricated control show similar relative performance as in Graph #2.



Graph #3. Force Measurements Blowing Through 300 ft With 200 deg of Bend

A comparison of Graphs #2 and #3 is of interest. Remember that these are the same conduits arranged in different configurations. Graph #4 presents this comparison for lubricants A, E and the unlubricated control.

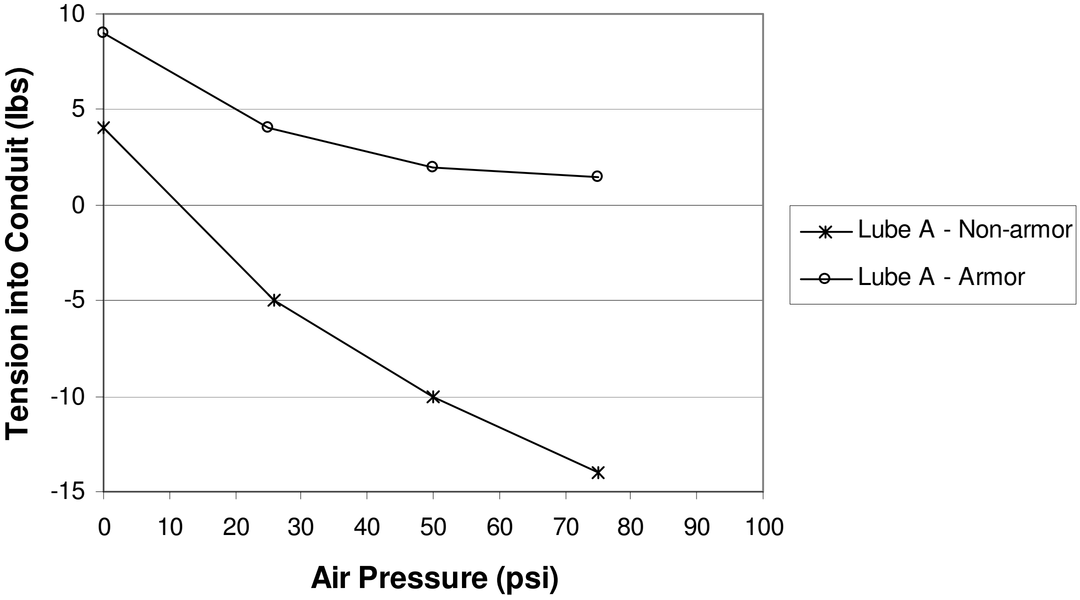


Graph #4. Force Measurements Comparing 300 ft and 220 deg of Bend With 300 ft and 720 deg of Bend

We see that the forces required for the 220° configuration are generally lower than the 720°, as we intuitively expect. These differences are greater at 100 psi than 25 psi, indicating some involvement of air flow or pressure in performance around bends. While high speed laminar air flow clearly minimizes the effect of bends, it does not eliminate them.

CABLE SIZE/FLEXIBILITY DIFFERENCES

Although the experiment was not designed to cover differences in cable types (jacket, flexibility, size, etc.), we did test one armored cable of the same jacket type as the standard test cable. It was only slightly larger (OD = 0.50″), but almost 50% heavier (115 lbs/M ft). It was blown through the 220° configuration with prelube A. The comparison (non-armored vs armored) is presented in Graph #5.

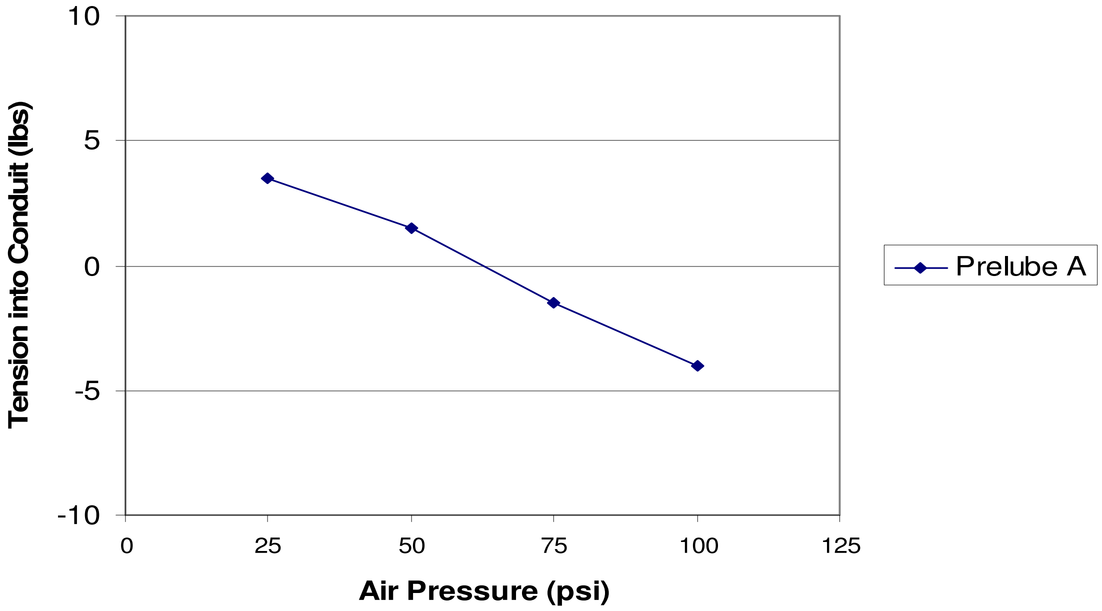


Graph #5. Force Measurements Blowing Through 300 ft
With 220 deg of Bend

The differences between the cables are substantial. It takes 6 to 8 times the air pressure to move the armored cable. With the same jacket, prelube, and conduit, we know the coefficient of friction should be the same, so it should take less than twice the force to move the cable. We're in the right range when there is no air flow. But once the air forces are introduced, the gap widens substantially. The difference shows the magnitude of the cable "stiffness" factor. Cable stiffness appears to be even more significant for long length blowing installations than friction coefficient. There is one offsetting factor, which we did not try to quantify. Presumably, the stiffer armored cable can handle more pushing force before buckling, so it can accept a stronger push from a mechanical pusher.

LONGER RUNS

The lowest friction lubricant (Prelube A) was chosen for a 1000 foot run test. At this distance, even with full air, the cable could not be threaded "dry". We were already past the maximum blowing distance for this combination. Graph #6 presents the data with the prelube only. The thousand feet of conduit was set up with 200° of bend (90° at the front and slightly over 90° about ⅔ of the way through.)



Graph #6. Force Measurements Blowing Through 1000 ft with 200 deg of Bend

As Graph #6 shows, the cable could not be pushed without air flow, so there is not data point at 0 psi. Note that 100 psi was now possible at full air volume. The longer conduit run resulted in more back pressure.

The line in Graph #6 is typical of those on the shorter lengths, but it has shifted to the right considerably. The point at which it crosses the x axis is slightly over 60 psi, versus 10 to 20 psi for the shorter runs. Presumably this is the point where the blowing force equals the frictional force.

SUMMARY

The measurement method developed shows significant differences in the performance and friction character of lubricated ducts versus non-lubed ducts. Significant differences can also be seen among lubricants, with the Prelube A being the optimal.

While the test method could work as a "screening" mechanism to determine the blowing character of cables, ducts, lubricants, etc., it is both elaborate and expensive to run.

We were disappointed that we could not carry out the analysis using existing models. Additional work needs to be done in this area. Better models would allow this and other data to be used in planning and optimization of blowing installations.

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