Blow Simulation Test to Measure Coefficient of Friction Between Microduct & Cable

Presented at
54th IWCS/Focus™
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For microduct cabling, a blowing test is needed to guarantee good blowing performance. Measurements of the coefficient of friction (COF) between microduct and cable (or fiber unit) could serve as a quick alternative for blowing tests. Such tests would require less material and there would be no need to have a test trajectory. The blowing length in practical situations is then calculated from theory (software exists which is based on this theory), taking into account cable, microduct and equipment properties and the typical undulations and bends in the trajectory. Many different techniques to measure the COF are used: wheel tests (different variants), sloped microduct and cable tests and the bullet test from **British Telecom**.

This article lists the shortcomings of these techniques. The correlation with blowing reference tests is poor, and this is discussed in *IEC 86A WG3*, concerning the draft specification for microduct cabling. The only reliable tests up to now have been the blowing reference tests. For blown fibers (not cables), it is possible to perform such tests with the microduct on drum.

A new technique, a blow simulation test, measures the COF between microduct and cable. With this technique, the cable is moved back and forth in a 17.1 m long microduct while air is forced through. At the same time, the force to move the cable is measured. The cable-moving equipment and force-measuring device are placed in a pressure chamber. The flow is such that real blowing conditions are simulated, e.g., the input and output pressures are the same as for a window of the same length in a blowing reference test. In this test, the magnitudes of air-propelling force and COF can be acquired separately, showing, e.g., the effect of textured cable surfaces. Tests so far have shown excellent correlation with blowing reference tests, also in cases where the wheel test failed.

Existing Test Methods

A summary of existing test methods to measure the COF between a cable and a microduct is as follows:

Wheel Tests. A cable sample with attached weight is pulled through a microduct sample around a wheel and the pulling force is measured. Several variants are used with different weights, diameters and angles over which the microduct is pulled over the wheel. Sometimes a pulley is also used to direct the cable in line with the pulling/force-measuring device. For example, one variant for use with microducts involves a wheel with radius R of 52 cm (1.7') placed before a pulling/force-measuring device, e.g. an **Instron** or **Zwick**, see **Figure 1**. The microduct sample is wound firmly around the wheel over 360°. The free angle ϕ for both microduct ends is about 10° (to minimize the effect of bending a cable with stiffness from straight to curved). A weight of which the mass M is about the mass of a length of 2 m of the cable sample is attached to the cable. The force F to pull the cable through the duct at 1.0 or 1.8 mpm speed after 20 cm of pulling is measured. A new clean, grease-free cable sample must be used to test every other duct sample. Sometimes a dummy cable with the same weight, but a lower stiffness than the cable to be tested, is used to minimize stiffness effects at the ends of the microducts. The COF can be calculated as in **Formula 1**:

$$F = (Mg + W\Delta l)\exp(2\pi f) + \frac{2f}{1+f^2}WR[\exp(2\pi f) - 1] \quad 1$$

Here W is the cable sample weight per unit length, g the acceleration of gravity (9.81 mps²), Δl the length of cable outside the duct circle, R the radius of wheel, M the mass of the weight and f the COF. The value of f can be calculated by iteration. Friction is average of the third, fourth and fifth measurements.

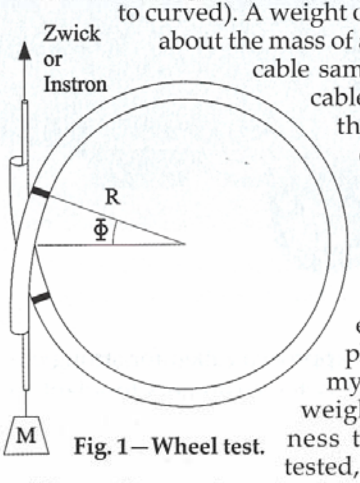

Fig. 1—Wheel test.

To best simulate the friction in blowing practice, the attached weight will be small. This is the reason that **Formula 1** is a little intricate (tests with different angles require different formulas), the simple exponential formula gives errors that are too large. The low forces involved also do not allow the use of (relatively small diameter) pulleys, where bending the cable, dissipating energy, results in extra forces.

Slope Tests. Two simple slope tests are the sloped microduct and sloped cable tests. They are easy to construct and are also available on the market.

In the sloped microduct test, a microduct sample incorporating a short cable sample is mounted straight on a clamping device. The angle α with the horizontal at which the cable starts sliding is measured. The COF f simply follows from **Formula 2** and **Figure 2**:

$$f = \tan(\alpha) \quad 2$$

Care must be taken that the length of the piece of cable is small enough. The (intrinsic) bend radius of the cable shall not result in touching opposite walls of the microduct, which would result in extra friction due to spring action of the cable ends. The cable samples must be started by hand for the best result. This test is used mainly for traditional optical cables and ducts.

In the sloped cable, a piece of cable, over which a short piece of microduct is sleeved, is mounted straight, under a little tension, in a clamping device. The angle α with the horizontal at which the microduct starts sliding is measured. Also here the COF *f* follows from **Formula 2**. The sloped cable test is seen in **Figure 3**.

Again, care is taken that the length of the piece of microduct is small. The bend radius of the microduct will not result in touching the cable with opposite walls of the microduct, which would result in extra friction due to spring action at the duct ends. Longer lengths are possible when using a straight metal cylinder around the microduct sample, which at the same time serves as a (small) weight. The microduct samples must be started by hand for best result. Test is used for smaller types of cable, like microduct cables.

Bullet Test. Here a brass slider is shot through a curved piece of microduct and the speed difference between two points is measured. Force analysis shows the side wall forces fall outside the window for the normal force per unit of length in a COF measurement for microduct cabling. The test cannot distinguish between different constructions of cable or fiber unit.

Results for Existing Test Methods

Wheel tests are expected to give the right values for the COF, when using the proper weights, eliminating small diameter pulleys and using the right formulas. Also for slope tests, when using the proper weight around the microduct sample in the sloped cable test, give those expectations. Users of said tests also claim good correlation between the measured COF and the blowing performance. However, the comparison found for different cable and microduct samples (next paragraph), with different lubrication procedures, does not always show good correlation. Here the COFs calculated from blowing reference tests can be much higher than measured with the wheel test described in this article (see **Figure 4** and text below). For this reason, a decision was taken in *IEC 86A WG3* not to incorporate tests to measure the COF in standards, but to write a separate technical document.

Tests to measure the COF have been done on different 3.9 mm (0.15") cables and 7/5.5 mm microducts with the wheel test described in this article. The microducts were either dry, with low-friction liner or prelubricated. Tests have been performed with or without lubrication of the microducts before blowing.

Blowing reference tests have also been performed. They were done in a trajectory about 1500 m long with 125 m long loops and in between them 180° bends of 0.25 m radius. Blowing pressure is kept at 10 bar and the experiment is stopped when blowing speed drops below 20 mpm. COF was calculated from the blowing distance using Draka software, which takes into account filling of the duct by the cable. As the software cannot handle the separate bends, this is simulated by windings with amplitude of 10 cm and period of 5 m (same as for 180° bends of 0.25 m radius every 125 m.

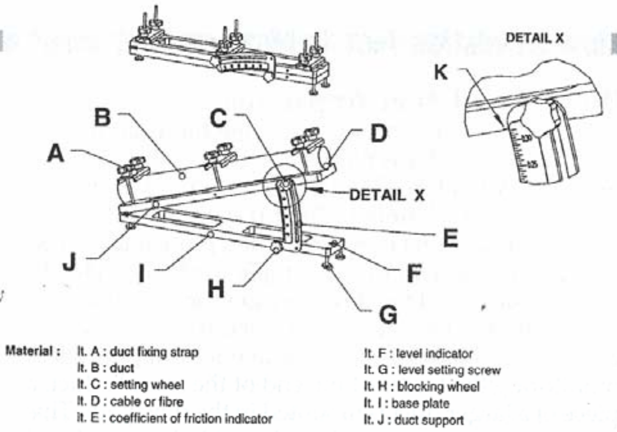

Fig. 2—Sloped microduct test.

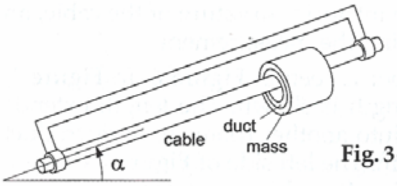

Fig. 3—Sloped cable test.

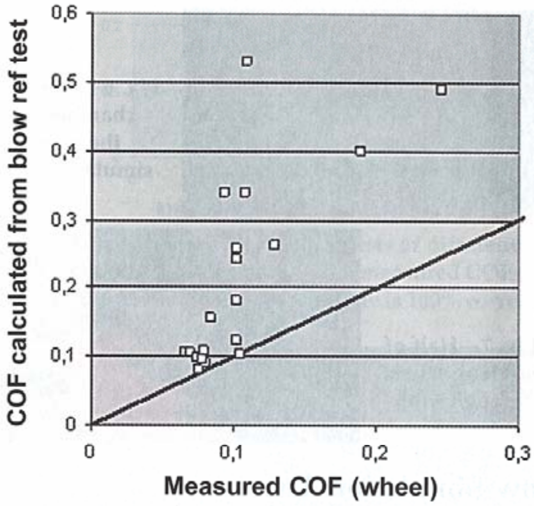

Fig. 4—Calculated COFs from blowing reference tests of different cables in different microducts, plotted against measured COFs (wheel test) Line is 100% correlation.

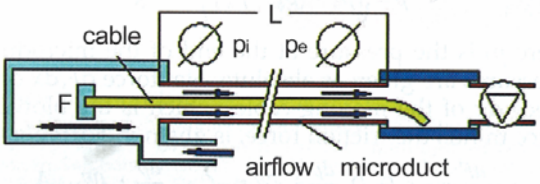

Fig. 5—Blow simulation test.

No points are found under the line in **Figure 4**. This means combinations of cables and microducts never perform better in blowing than they do with the wheel test. But, many combinations perform less than the wheel test, especially those with microducts with no extra lubrication. For the well-performing combinations, the correlation with the blowing reference tests is good. Test methods to guarantee good blowing performance should also measure effects of tacky lubricants and nonstraight cables having little space. This can only be done with blow simulation.

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Blow Simulation Apparatus

Figure 5 (previous page) shows the blow simulation test. A sample cable is placed in a sample microduct of length *L*. Air is forced to flow through the microduct via a pressure chamber. The pressure and flow are controlled such that pressures p_i and p_e are maintained at the inlet and exit of the sample duct, respectively. The pressures and the flow are monitored. In the pressure chamber, the cable is attached to a force sensor and moved back and forth at about 20 mpm, while monitoring the force. At the end of the sample duct, a piece of a larger duct is mounted in the flow path. This equalizes the pressure when the cable is moved and air is pushed aside. It also minimizes the effect of friction caused by the intrinsic curvature of the cable, an end effect disturbing the measurement.

A pressure chamber is seen in **Figure 6**. In **Figure 7**, half of the test length is shown. The length extends through the wall into another room. Total microduct test length is 17.1 m. The left side of **Figure 7** shows a pneumatic extension for cable movement.

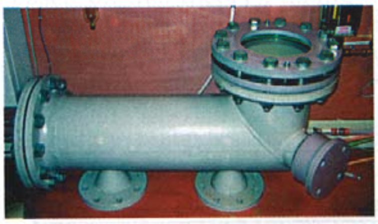

Fig. 6—Pressure chamber of the blow simulation test.

Fig. 7—Half of test length (rest through wall).

Blow Simulation Theory

When blowing a cable with pressure p_0, the pressure *p* as a function of position *x* over the length *l* is given in **Formula 3**:

$$p=\sqrt{p_0^2-\left(p_0^2-p_a^2\right)\frac{x}{l}} \qquad 3$$

Here p_a is the pressure at the end of the microduct. Pressures are given as absolute. Net force d*F*/d*x* on a piece d*x* of the moving cable, which is the blowing force minus the friction force, is given in **Formula 4**:

$$\frac{dF}{dx}=-\tfrac{\pi}{4}D_d D_c\frac{dp}{dx}\pm fW\equiv -C_{blow}\frac{dp}{dx}\pm fW \qquad 4$$

Here *W* is cable weight per unit of length, *f* is the COF between cable and microduct and D_d and D_c are inner diameter of the microduct and outer diameter of the cable, respectively. For forward movement, the sign of the friction force is negative, for backward movement positive, while a tensile force is positive. The pressure, blowing force and friction force on the cable are given in arbitrary units in **Figure 8**. Friction force is given at the same scale as blowing force for a typical jetting (synergy of blowing/pushing) installation.

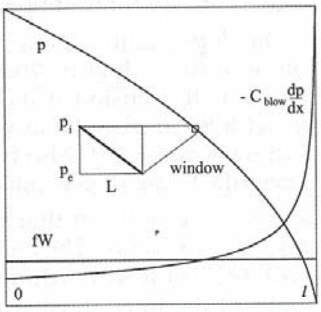

Fig. 8—Pressure *p*, blowing force C_{blow} x d*p*/d*x* and friction force *fW* as a function of the position in a duct of length *l* in a blowing reference test. Windows of length *L*, with pressure p_i and p_e at inlet and exit, respectively, are taken for the blow simulation test.

In a blow simulation test the parameters are chosen the same as in the blowing reference test. Take samples of the cable and the microduct and copy the lubrication process (if any). Then choose the same conditions for the airflow. Length *L* of the samples will be large enough that onset of flow occurs at a relative short length and flow can be considered fully developed. Also the Reynold number R_e will be the same as in the practical installation. For turbulent flow (Blasius equation) the number results from **Formula 5**:

$$R_e=2.9\frac{D_h^{12/7}}{\mu^{8/7}}\left(\rho_a\frac{p_i^2-p_e^2}{2Lp_a}\right)^{4/7} \qquad 5$$

Here, μ is the dynamic viscosity of the flowing medium (1.8 10^{-5} Pas for air) and ρ_a its density at atmospheric pressure (1.3 kg/m³ for air), D_h the hydraulic diameter (D_d with correction when filled with cable) and p_i and p_e the pressures at the inlet and exit of the length *L*, respectively (note that R_e is constant over the entire duct length when its hydraulic diameter is constant). It follows that exact copies of both forces on the cable and flow properties can only be obtained by cutting out windows from **Figure 8**. The relation between p_i and p_e is then found using **Formula 6**:

$$p_i^2-p_e^2=\frac{L}{l}\left(p_0^2-p_a^2\right) \qquad 6$$

For a moving cable in a straight length *L*, on which the pressure drop can be approximated linearly, and for a tensile force on the cable (*F* positive), the COF follows from **Formula 7**:

$$f=\pm\frac{\frac{\pi}{4}D_d D_c\left(p_i-p_e\right)-F}{WL} \qquad 7$$

The positive sign represents forward movement and the negative backward. With forward movement, the force may also be compressive, where *f* is found numerically. When the air propelling factor C_{blow} is given by the theoretical expression in **Formula 4**, the COF for forward and backward movement is the same. If the air propelling force is also influenced in some other way, different and hence wrong results are found. In this case, C_{blow} is regarded as unknown. From the two equations (forward/backward) the two unknowns *f* and C_{blow} are found per **Formula 8** and **Formula 9**:

$$f=\frac{F_b-F_f}{2WL} \quad 8 \qquad C_{blow}=\frac{F_b+F_f}{2\left(p_i-p_e\right)} \quad 9$$

Here F_f and F_b are the forces measured in forward and backward movement, respectively.

Blow Simulation Test Results

Blow simulation tests were conducted on 7/5.5, 10/8 and 12/9.6 microducts with different cable types at pressures as listed in **Table 1**. These tests represent windows of 17.1 m on a length l of 1500 m and a pressure p_0 of 10 bar at the beginning of this length, p_i and p_e obtained with **Formula 6**. Relative positions x/l are given for these windows in **Table 1**.

Table 1. Pressures for 7, 10 and 12 mm microducts.

x/l	0.45	0.60	0.75	0.90	1.00
p_i (bar)	7.18	6.00	4.56	2.61	0.54
p_e (bar)	7.10	5.90	4.44	2.41	0.00

The samples were taken from blowing reference tests where COF was calculated the same as in **Figure 4**. Field test and the blow simulation test results are given in **Figure 9**. Microducts with too little (none) or too much lubricant were also used to get more information about the validity of the blow simulation test.

In **Figure 10**, wheel test results are from the same samples as in **Figure 9**. There is little correlation between measured COF here and the blowing reference test COF, while the blow simulation test showed good correlation in **Figure 9**. Small deviations in **Figure 9** are attributed to uneven lubrication over the length of the blowing reference tests, as observed in blow simulation tests on samples taken from different locations. A blow simulation reference test gives one COF value; blowing tests give different local values.

The blow simulation tests also give data on air drag force, which varies between the same as resulting from the existing blowing theory and 10% more. No significant correlation of air drag force and cable or microduct roughness has been found in our experiments. Changing either the roughness of the cable or the microduct has in some cases led to increased blowing performance (much more than 10%), leading to the conclusion that this had affected the COF rather than air drag force. Blowing theory is then confirmed as a good tool to forecast blowing performance.

The blow simulation test has helped further improve microduct cabling and its installation. One development is the cable lubricator (**Figure 11**). Its use corresponds to the most left point in **Figure 9** (COF of 0.06, really effective now; value was measured often in a wheel test). Not only could the 1500 m blowing reference test be done at low pressure, but also a new record in microduct cabling was achieved, where a 24-fiber cable (3.9 mm) was blown with a cable lubricator into a 7/5.5 mm microduct over a length of 3.5 km in one shot.

Conclusions

Existing ways to measure COF between cable and microduct such as the wheel test can't guarantee good blowing performance. The alternative blow simulation test involves a cable that is moved backward and forward in a microduct with airflow, simulating a window in a real installation. The measured forces supply data on both friction and air drag force. Measurements show good correlation with blowing. Air drag force is the same or 10% more than would result from blowing theory, confirming this theory.

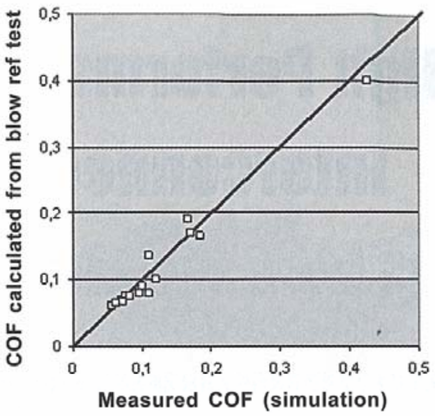

Fig. 9—Calculated COFs from blowing reference tests of different cables in different microducts, plotted against measured COFs with blow simulation test. Line is 100% correlation.

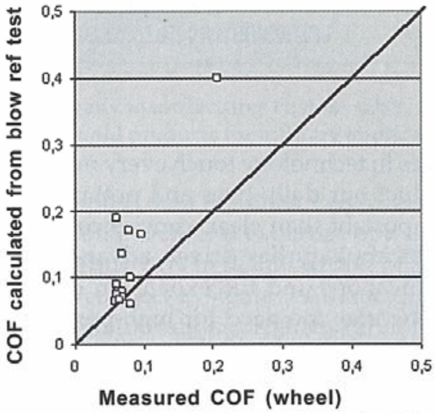

Fig. 10—COFs from blowing reference tests of different cables in different microducts, plotted against measured COFs with wheel test. Samples same as Figure 9. Line is 100% correlation.

Fig. 11—Cable blowing equipment (blue) and cable lubricator (red) at work during one-shot 3.5 km blowing of a 24-fiber cable into 7/5.5 mm microduct.

Author Biographies:

With a Ph.D. from the **Technical University of Eindhoven** (Netherlands), **Willem Griffioen** is Product Manager at **Draka Comteq Telecom** in Gouda, The Netherlands. He also worked at **KPN Research** in R&D of outside plant and installation techniques and at **Ericsson Cables** in exchange and joint projects with KPN Research.

Sito Zandberg joined Draka Comteq as a Production Engineer in 1987. In 1992, he became head of the lab that checks all incoming goods. Today, he works as a Production Material Engineer and is responsible for new materials and cables, troubleshooting and testing of microducts, cables and COF measurements.

Menno Versteeg has been a System Engineer at Draka Comteq Telecom since 2001. Prior to that, he worked at **ESA-ESTEC**, **Fokker Space** and **TNO-TPD**, where he was Head of Technical Support in the Optical Components and Thin Layers Department.

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