A New Fiber Optic Life for Old Ducts

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Abstract

Systems are described where loose bundles of 7 and 10 mm mini-tubes are jetted into ducts. In these mini-tubes, which can be coupled together into long routes including branches, micro-cables with up to 72 fibers each can be jetted in. These high performance mini-tubes allow jetting of the cables over 2500 m (8000') per single blow, thus offering the possibility to upgrade old ducts. Bundles of mini-tubes can also be installed in ducts occupied with one or more resident cables. Different trials and projects are described in this paper.

Keywords

Optical fiber; cable; duct; mini-tubes; jetting/blowing; additional jetting/blowing; resident cables; upgrading old ducts.

1. Introduction

Civil works are the largest cost contributors for fiber optic installations when existing ducts cannot be used anymore. Often new ducts have to be installed along existing ducts. The latter ducts may be of bad quality, not meeting requirements for long length fiber optic installation, or contain resident cables. Many duct routes have been built for copper telecom networks. Here short lengths of cables were pulled in with high forces and numerous splices were made to connect them.

Fiber optic cables are installed now over much longer lengths, on the order of 10 km between splices. Modern ducts are of improved quality resulting in lower coefficient of friction (COF) between cable and duct. Together with the development of the jetting (blowing) technique [1] this resulted in cost-efficient installation of fiber optic cables over the required lengths. Old ducts suffer from high COF, especially after long-term aging. They are often not able to withstand the air pressures needed for cable jetting. Moreover the sections are of short length. Numerous duct connections must be made to allow installation of long cable lengths. This is especially a problem when the ducts were cut immediately after entering the handhole, making it almost impossible to connect the ducts sufficiently pressure-resistant to allow jetting. All these problems are faced to a larger extent when resident cables occupy the ducts.

Installing loose bundles of mini-tubes (7 or 10 mm external diameter) [2] in old ducts are a way to overcome the above-mentioned problems. These mini-tubes are installed by jetting with, in most cases, low air pressures. In this way long continuous upgraded tube routes are obtained with low COF and high pressure-resistance. In each mini-tube cables with up to 72 fibers can be installed. It is also possible to install loose bundles of mini-tubes in used ducts with traffic along resident cables. Tables are given for several combinations of additional tube jetting. Validity of this table has been obtained from trials and experiences with projects.

2. Mini-tubes Systems

Mini-tube systems consist of loose bundles of mini-tubes (outer diameter 7 and 10 mm), see Figure 1. These bundles can be jetted (synergy of pushing and blowing) in ducts such as used today for installation of fiber optic cables. Jetting lengths for tube bundles are typically 200 m (700') per bar air pressure. In good quality ducts more than 1500 m (5000') can be reached "in one blow" and less for ducts with resident cables. Bundles of mini-tubes can be coupled by means of simple connectors. Branching of one or more of the mini-tubes is possible by making a window-cut in the duct, cutting the mini-tube of choice and connecting it to a branching mini-tube. The ducts are recovered by using a (split) clip-on Y-connector, see Figure 2. This operation can be done without risk of damaging the other mini-tubes. Micro-cables with extremely high fiber-density (up to 72 fibers) can be jetted in these mini-tubes, each cable having its individual path through the network, without the need to make splices in the optical fibers.

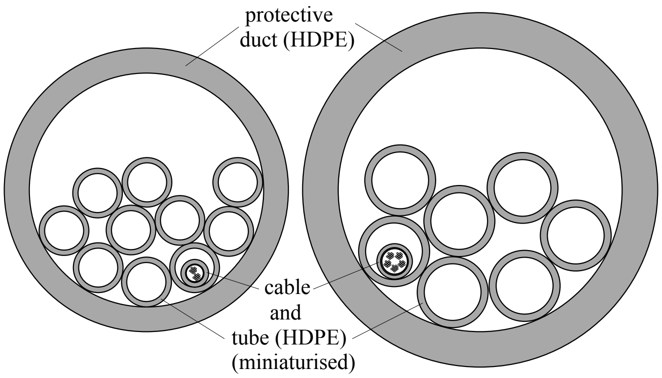

Figure 1. Typical bundles of mini-tubes with cables, left 40/33 mm (1¼") duct with 10 tubes of 7 mm and a 24-fiber cable, right 50/40 mm (1½") duct with 7 tubes of 10 mm and a 72-fiber cable

Jetting technology allows installing lengths of the cables of up to 2500 m (8000') "in one blow". With cascaded jetting (tandem, see Figure 3) and buffering techniques (see Figure 5) more than 8 km (5 miles) splice-less cable lengths have been installed.

Figure 2. Y-connector to branch mini-tubes

Figure 3. Jetting micro-cables in tandem

Some advantages of systems with loose bundles of mini-tubes are:

- Investments grow with demand.
- Installation of latest fiber optic technology.
- Midspan-access at any place and any time. Fibers with traffic not disturbed.
- Fast installation technology and short response time.
- Possibility of re-routing without lost fibers or splicing.
- Mini-tubes upgrade old ducts. Low coefficient of friction and high pressure-resistance improve jetting. Long continuous routes can be made.
- Mini-tubes easily jetted in ducts with resident cables.

The number of mini-tubes is advised to be such that half the space of the duct is filled, see Table 1. In this way the duct still gives the required mechanical protection (impact resistance) and Y-branching and jetting of the bundle are made easy.

Table 1. Recommended maximum number of tubes and fiber counts for different ducts

duct (mm)	10 mm tubes	max fibers	7 mm tubes	max fibers
63/50 (2")	10	720	20	480
50/40 (1½")	7	504	14	336
40/33 (1¼")	5	360	10	240
32/25 (1")	3	216	7	168
25/20 (¾")	1	72	3	72

3. Additional Jetting

When there is a demand for a new connection and the available ducts are used significant civil costs have to be made. Therefore one tries to use the free space in ducts already occupied with resident cables. Pushing and pulling with rodders can do this, but in many cases the lengths are short. Another technique, additional jetting of cables, can in many cases also be done, again only over short lengths. Even when the intermediate distance between handholes can be bridged these short lengths cause problems. Because fiber optic links require long splice-less lengths such installations are not economical. Additional installation of mini-tubes does not show this drawback when intermediate distances between handholes can be bridged. The tubes can simply be coupled and long continuous tube routes of high quality (low friction, high pressure resistance) are formed.

Additional jetting of mini-tubes appears at first sight comparable to additional jetting of cables: on the one hand the tubes are more lightweight, but on the other hand the wedging of the smaller tubes seems to be more severe. The latter turns out to be not true! When the diameter of the second cable becomes larger it comes out of the wedge first, but for still higher diameters the wedging effect increases again, especially close to the situation called jamming (see Appendix A). In many practical situations the wedge effect for mini-tubes is less than for cables. Moreover the tubes are much lighter so the jetting distances are much higher. Theoretical distances, confirmed at Draka Comteq's jetting test-site at Delfzijl (Netherlands), are given for 7 and 10 mm tubes in Tables 2 to 5.

Table 2. Jetting distances for 10 mm tubes in 40/33 mm (1¼") duct, different numbers and resident cables

cable 1 (mm)	1 tube	2 tubes	3 tubes	4 tubes
12 (0.47")	1200 (4000')	1100 (3600')	950 (3100')	800 (2600')
15 (0.59")	700 (2300')	600 (2000')	550 (1800')	
16.5 (0.65")	400 (1300')	400 (1300')		
18.5 (0.73")	200 (700')	200 (700')		

Table 3. Jetting distances for 10 mm tubes in 50/40 mm (1½") duct, different numbers and resident cables

cable 1 (mm)	1 tube	2 tubes	3 tubes	4 tubes	5 tubes	6 tubes
12 (0.47")	1600 (5200')	1500 (5000')	1300 (4300')	1150 (3800')	1000 (3300')	900 (3000')
15 (0.59")	1200 (4000')	1100 (3600')	1000 (3300')	850 (2800')		
16.5 (0.65")	800 (2600')	800 (2600')	750 (2500')	700 (2500')		
18.5 (0.73')	400 (1300')	400 (1300')	400 (1300')	400 (1300')		

Table 4. Jetting distances for 7 mm tubes in 40/33 mm (1¼") duct, different numbers and resident cables

cable 1 (mm)	1 tube	2 tubes	3 tubes	4 tubes	5 tubes	7 tubes
12 (0.47")	900 (3000')	1000 (3300')	1000 (3300')	1000 (3300')	900 (3000')	800 (2600')
15 (0.59")	350 (1200')	450 (1500')	500 (1600')	500 (1600')	500 (1600')	450 (1500')
16.5 (0.65")	250 (800')	250 (800')	300 (1000')	300 (1000')	300 (1000')	
18.5 (0.73")	200 (700')	200 (700')	200 (700')	200 (700')		

Table 5. Jetting distances for 7 mm tubes in 50/40 mm (1½") duct, different numbers and resident cables

cable 1 (mm)	2 tubes	5 tubes	7 tubes	9 tubes	10 tubes	12 tubes
12 (0.47")	1600 (5200')	1350 (4400')	1200 (4000')	1050 (3400')	950 (3100')	600 (2000')
15 (0.59")	700 (2300')	850 (2800')	750 (2500')	600 (2000')	550 (800')	400 (1300')
16.5 (0.65")	400 (1300')	500 (1600')	450 (1500')	400 (1300')	350 (1200')	
18.5 (0.73")	200 (700')	250 (800')	250 (800')			

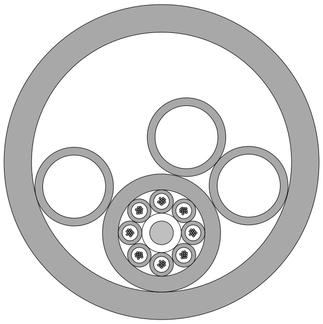

Figure 4. 40/33 mm (1¼") duct with 15 mm (0.59") resident cable and 3 tubes 10 mm

In Figure 4 an example is shown of a 40/33 mm (1¼") duct occupied with a 15 mm resident cable in which 3 additional 10 mm tubes were installed (possible over 550 m, see Table 2). Note that the partial filling of the duct with cable and tubes still guarantees resistance against impact. 10 mm corresponds to about the minimum wedge factor, see Figure 13. The 3 tubes can store 3 cables with up to 72 fibers, a total of 216 fibers. An additional cable with this fiber count would be very difficult to install.

4. Projects

4.1 San Diego

A reference project (i.e. with good quality ducts and no resident cables) is installation of 10 tubes of 10 mm in empty 60/50 mm (2") ducts between San Diego and Phoenix. Bundles were installed in lengths of about 1000 m (3000'), usually a few of those sections per day. Many splice-less lengths of 8 km (5 miles) of 60-fiber cable have been installed (one-day jobs), using tandem jetting and buffering (see Figures 3 and 5). Note that this installation was done with loops of cable-overlength stored in handholes about every 400 m (1300').

Figure 5. Jetting micro-cables with buffering

4.2 Upgraded Duct Trials and Projects

In Wuhan (China) a trial was done in thin-walled 32 mm (1") PVC duct. Here 7 tubes of 7 mm were installed over 500 m (1600') using only 2 bars. More pressure was not allowed. Expansion of the ducts and serious leaking already occurred. The newly installed mini-tubes eliminate these problems.

In Geneva the above ground part of the optical network of CERN needs extra fiber capacity (replacement) for new experiments. The 52 mm (1½") ducts are of such quality (high friction, probably with leaks and immediate cut at handhole entrances) that burying new ducts was considered. Instead mini-tubes can be installed easily with handholes about every 500 m (1600'). After coupling of the tubes long spliceless cables can be jetted in.

4.3 San Jose

A short but challenging installation was done in San Jose, California. Here an installation was requested over 400 m (1300') in a 42/34 mm (1¼") duct with 2 resident cables (12 and 15 mm) with traffic. The civil and permitting costs that would be involved in digging up this portion of the route was prohibitive. Previous to our arrival several attempts, including the use of rodders, were done to install a third cable, all without success. Shown in Figure 6 is the duct with cables in the handhole. Note the damage to the duct, caused by the rodder (right in the picture). Some debris (only a small portion of the total encountered) can be seen at the end of the rodder, caused by scraping against the duct wall.

Because the duct was of poor quality it was decided to install only one 10 mm tube next to the cables (in good condition additional jetting of 2 tubes would be possible over 600 m (2000') in this geometry). During installation several additional problems were encountered. First the duct was leaking halfway. Next obstructions were present at three different locations in the duct, probably caused by debris from previous attempts with rodders. Finally also no aftercooler was present with the compressor, resulting in temperatures of about 60 degrees Celsius (140 degrees Fahrenheit) of the airflow, softening all materials. Nevertheless the tube could be installed and a 48-fibre cable was blown in immediately after. The whole project was finished in slightly more than two days, including splicing to other cables. The majority of time was spent cleaning from previous attempts. Actual installation of the guide tube and cable took only 1/2 day.

Figure 6. Duct occupied with 2 resident cables

Figure 7. Mounting Y-piece for additional jetting with 2 resident cables and guide for the tube

Figure 8. Installed additional tube and cable

4.4 Gothenburg

On a trajectory of about 3 km (2 miles) near Gothenburg, Sweden there was a demand for extra fiber capacity. Here a fiber optic cable with a diameter of 14 mm was already present in a 40/33 mm (1¼") duct. An initial attempt to install an additional 96-fibre cable with a diameter of 15 mm was not successful in that it only reached 150 m (500'). Instead 3 tubes of 10 mm were jetted in (see Figure 9). This was installed in slightly more than 2 days, with lengths per blow of up to 512 m (1680'). This length is somewhat less than expected. This might be caused by the fact that a lot of water was present in the duct, caused by the many duct openings resulting from the previous trials with cable.

In each of the 10 mm tubes a cable with up to 72 fibers can be jetted in easily (up to 2500 m or 8000' in one blow). One cable was successfully installed, without splice, jetted with one master and one tandem-jetting device.

Figure 9. Additional jetting of 3 tubes of 10 mm

4.5 Copenhagen

A trajectory of 1137 m (3730') of 32/27.2 mm (¾") duct was occupied with a single resident 12 fiber cable with diameter of 10.9 mm over 755 m (2477'). Over a length of 32 m (105') even 2 resident cables were present. In the free duct section a bundle of 4 tubes of 10 mm was jetted in. In the section with single resident cable a bundle of 2 tubes of 10 mm was installed in a single blow. The same bundle was pushed in by hand over the remaining double occupied duct section. Next a 60-fiber cable was blown in over the entire length. The whole operation took half a day.

Figure 10. Additional jetting Copenhagen

4.6 Other Projects

In a trial in Chattanooga the water-jetting (floating) a bundle of 3 tubes of 10 mm over 1200 m (4000') in a 60/50 mm (2") duct with resident 288-fiber cable with a diameter of 20.4 mm was performed. Here also the same bundle was floated over 600 m (2000') in a 42/35 mm (1¼") duct with resident 96-fibre cable with diameter of 15.5 mm.

In Belgium a bundle of 3 tubes of 10 mm was successfully jetted over 1100 m (3600') into a 50/40 mm (1½") duct with resident 48-fibre cable with diameter of 12 mm.

5. Conclusions

Systems with loose bundles of 7 and 10 mm mini-tubes can upgrade old duct routes. The mini-tubes can easily be coupled to longer lengths in which micro-cables with up to 72 fibers per tube can be installed with high performance. Bundles of mini-tubes can even be installed in occupied ducts, next to resident cables with traffic. Installation lengths per blow are, surprisingly, much longer for additional tubes than for cable. In addition to this benefit longer lengths are achieved by using coupling of the tubes.

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7. References

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Appendix A: Wedge Factor

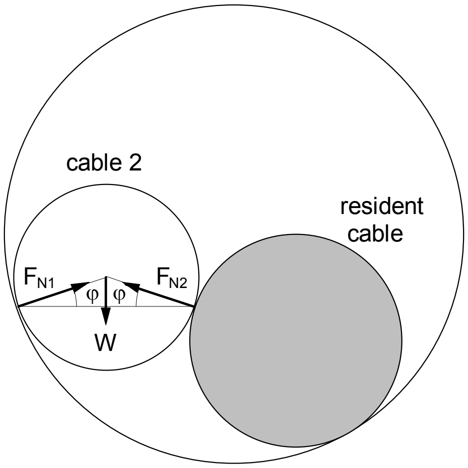

Figure 11. Forces on a second cable

When a second cable is installed in a duct next to a first (resident) cable it will experience higher friction forces because of the wedging effect. This effect is largest (worst case) in the situation that the weight W of the cable (or the resultant of the weight and other axial forces) is pointed symmetrically into the wedge, as indicated in Figure 11. From this Figure follows the wedge factor f_{wedge} , with which the friction force (proportional to the sum of the normal forces F_N acting on the cable) increases with respect to the situation of sliding over a flat surface:

$$f_{wedge} = \frac{1}{\sin(\varphi)} \quad (1)$$

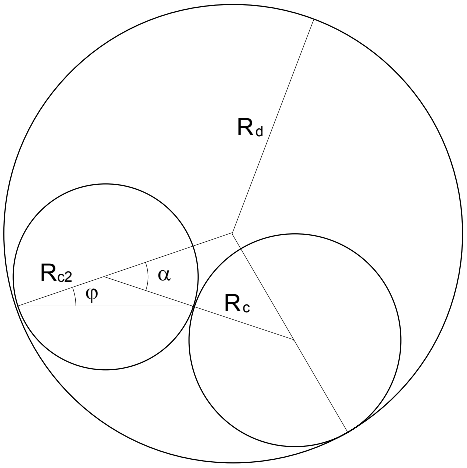

Figure 12. Parameters to calculate wedging

In Figure 12 parameters are given to further calculate the wedge factor, for clarity instead of the diameters D_d, D_c and D_{c2} for duct, first cable and second cable, respectively, the radii R_d, R_c and R_{c2}. The sum of the angles from the isosceles triangle with angles φ and the middle of cable 2 is equal to $\pi - \alpha + 2\varphi$. This sum is for every triangle equal to π, hence follows:

$$\alpha = 2\varphi \quad (2)$$

For the triangle with angle α, center of duct and center of first cable it follows using modified "Pythagoras" for angle α (instead of a right angle):

$$\begin{aligned}(R_d - R_c)^2 &= (R_c + R_{c2})^2 + (R_d - R_{c2})^2 \\ &\quad -2(R_c + R_{c2})(R_d - R_{c2})\cos(\alpha) \quad (3)\end{aligned}$$

Together with equation (1), using 1-cos(2φ) = 2sin^2(φ) and rewriting in diameters this leads to the simple expression:

$$f_{wedge} = \sqrt{\frac{(D_c + D_{c2})(D_d - D_{c2})}{D_{c2}(D_d - D_c - D_{c2})}} \quad (4)$$

This equation leads to the same results as the, much more intricate, set of equations in [3].

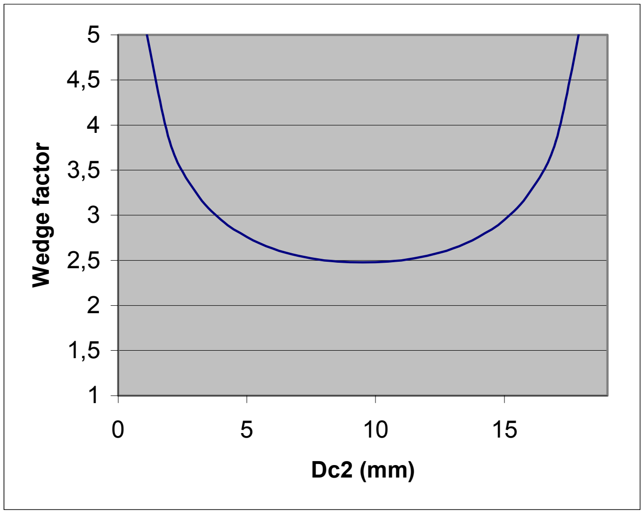

Figure 13. Wedge factor as a function of diameter D_{c2} of second cable for a 40/33 mm (1¼") duct with resident 15 mm cable

The minimum value for the wedging factor:

$$f_{wedge,\min} = \frac{D_d + D_c}{D_d - D_c} \quad (5)$$

is reached for an optimal diameter of the second cable:

$$D_{c2,opt} = \tfrac{1}{2}(D_d - D_c) \quad (6)$$

In Figure 13 an example is given of this wedging factor as a function of diameter of the second cable. Note the symmetry. The increase in wedge factor for higher diameters of the second cable can be understood by realizing that the walls in between which wedging occurs become parallel again for exact fitting of the second cable. This effect is also known as jamming, see e.g. [4].

Biographies

Willem Griffioen received an MS degree in Physics and Mathematics from Leiden University (Netherlands) in 1980 and worked there until 1984. He joined KPN Research, St. Paulusstraat 4, 2264 XZ Leidschendam, The Netherlands. Responsibilities R&D of Outside-Plant and Installation Techniques. He worked at Ericsson Cables, Hudiksvall (Sweden) and at Telia Research, Haninge (Sweden) in the scope of exchange/joint projects with KPN Research. He received his Ph.D. (Reliability of Optical Fibers) in 1995 from the Technical University of Eindhoven (Netherlands). Currently, since 1998, he is product manager at Draka Comteq - NKF Telecom, Zuidelijk Halfrond 11, 2801 DD Gouda, The Netherlands.

Willem Greven received his degree in advanced technical studies in Delfzijl in 1977. Since then he jointed Draka Comteq - NKF Telecom, IJzerweg 2, 9936 BM Farmsum (Netherlands). He worked at departments of paper-insulated cables, plastics, was quality inspector, co-ordinator final inspection and unit-leader plastics. Since 1996 he joined the team that develops and introduces the JETnet system as senior projects & systems engineer. He made demonstrations and pilot projects of the system all over the world.

Thomas Pothof joined Draka Comteq - NKF Telecom, IJzerweg 2, 9936 BM Farmsum (Netherlands) in October 1968. He started at the department of paper-insulated cables. Then he worked for some years as quality inspector in the plastics department. Next he was one of the pioneers in the optical cable department, in the function of group leader. After introduction of self-steering teams he became materials planner of this department. In October 2000 he joined the JETnet team as projects & systems engineer.