Cable Blowing – 35-Year Historical Review

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Abstract
Back in 1986, the Netherlands PTT was facing major problems to install optical cables for the backbone network into ducts. This was the trigger to develop the blowing technique for cables, inspired by British Telecom's blown fiber technology (1982) for flexible and lightweight fiber members. Now with recognition that fiber members do not need to be lightweight and flexible at all to benefit from air propelling forces. In fact a certain cable stiffness is needed, creating synergy of pushing and blowing (often called jetting), doubling installation lengths. The advantages are so clear that blowing has become the standard method for installation of optical cables into ducts. Improvement of cables, ducts and lubrication made blowing length increase and fiber count rise. The development of microduct cabling, relying heavily on blowing technology, has also been discussed, as well as some special spin-off applications.

Keywords: Optical fiber; cable; duct; pulling; blowing; jetting; compressed air; pushing.

1. How it All Started
Long time ago, in 1986, when the installation of optical cables into ducts for the backbone network began to take place on a large scale, the Netherlands PTT was facing major problems. Cable lengths were 2.1 km and they had to be pulled in one length, to avoid splices (at that time still a big effort). But, pulling length was limited to less than 300 m, so bad even that for flawless installation assistance was needed every 175 m, see Fig. 1. Installation was done from the middle, 1050 m in one direction split into 6 sections of 175 m, with a winch and 5 intermediate Figure-8 capstans, see Fig. 2. Then the remaining length from the drum was buffered into Figure-8's (also another buffering technique was used) prepared for installation in the other direction. Needless to say that this practice was complicated by sync issues. It often took a full day to install in one direction, leaving the remaining cable length on the drum overnight. Then sometimes the cable drum was gone next morning (copper thieves were not yet aware that optical cables do not contain copper.

Understanding why the cable could only be pulled over such short distances was lacking. Applying cable pulling theory, with gravitational friction on straights and capstan effect in bends, could by far not explain the limited pulling lengths. Suspect was the effect of cable stiffness in bends, for which no theory was found. So, the theory was developed at the Netherlands PTT. It turned out that indeed this effect contributed to pulling force build-up, but it could still by far not explain the limited pulling lengths [1]. Then it was recognized that straights were not fully straight, see Fig. 3. Undulations were present, and they were severe because relatively small 32/26 mm ducts were used (in e.g. Germany, where 50/40 mm ducts were used, there were no such extreme pulling issues).

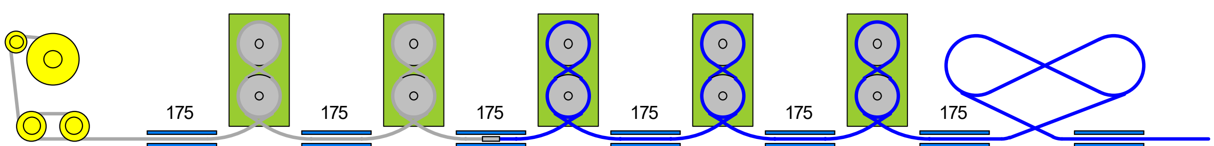

Figure 1. Installation of optical cables (2 x 1050 m) into ducts by pulling in The Netherlands in 1986

Figure 2. Figure-8 capstan

Figure 3. Open trench with undulating ducts

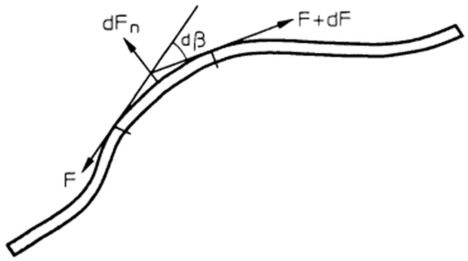

Figure 4. Direction changes in undulations

Like bends, these undulations contain direction changes, see Fig. 4, the true cause for the capstan effect. When also a theory was developed for undulations, present over the entire length, the limited pulling length could be quantitatively explained [1].

Knowing that the capstan effect in duct undulations was the cause of all problems, the blown fiber technique, developed in 1982 by British Telecom [2,3], was worth studying (as already mentioned in [1]), because with blowing the capstan effect is mainly suppressed (pulling force build-up limited because propelling forces of the high-speed airflow locally compensate gravity friction, avoiding force build-up). Problem was that blown fiber members had to be lightweight and flexible. However, since it was now known that the effect of the cable stiffness was not as large as initially thought, and could also be quantified, it was found theoretically that blowing of real cables could also be an option. So, time to try it! This was done in a 4-loop test trajectory, previously used to evaluate functioning of Figure-8 capstans in tandem operation, see Fig. 5.

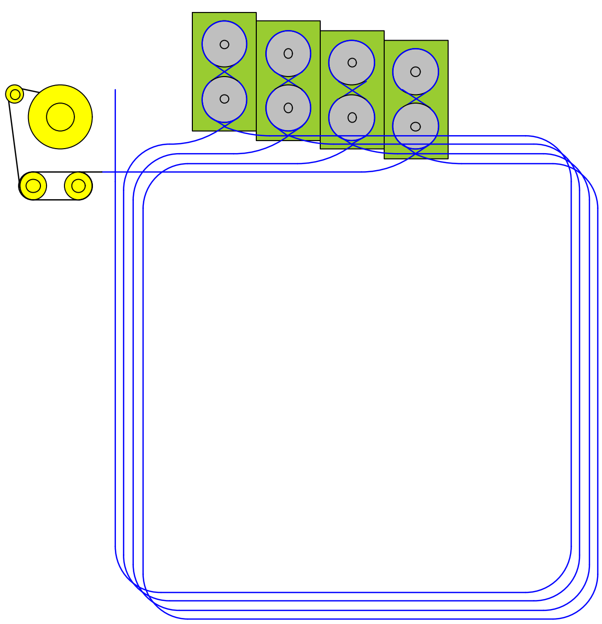

Figure 5. Trajectory used to evaluate Figure-8 capstans

As no equipment yet existed to blow cables, the air coupling to install the winch line was used, the feeding hole increased to the size of the cable. To overcome the backpressure force the cable had to be pushed in manually, see Fig. 6-middle. This was hard work, done by 4 persons in turn (we still missed the mechanical drive of Fig. 6-bottom, not only doing the work, but also positioned close to the pressure chamber, no variable free stroke with easy buckling of the cable). Some of them complained and did not believe it would work, one said it was tried already without success (but that was with a pig at the foremost end of the cable and no feeding force, see Fig. 6-top). However, after reaching one loop, they became quiet, and when the second loop was completed they called it a miracle! It was not (yet) a miracle, because 2 loops (the double of pulling) was forecasted already theoretically. As there were more loops the hard work was continued. Then loop 3 and finally the end of loop 4 was reached, now 2 times as far as forecasted theoretically!

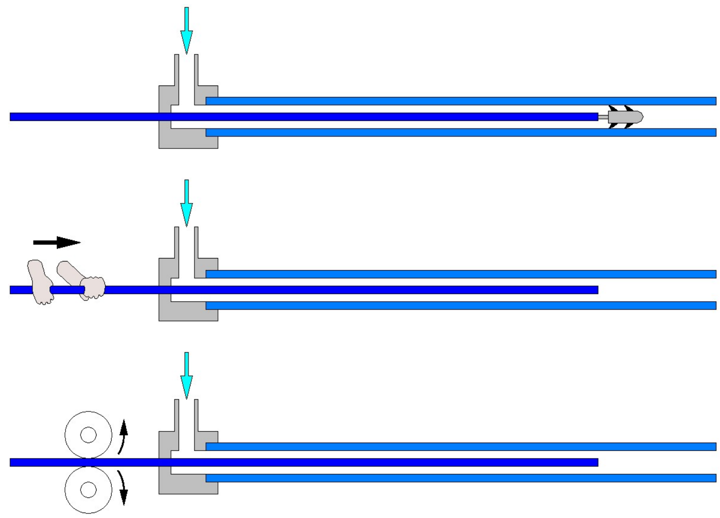

Figure 6. Manual test to evaluate blowing of real cables

Thinking it all over, it was found that the air propelling forces are not constant over the length, but increase towards the end because of expansion of the compressible air. If then you push harder than needed for compensation of the back-pressure force, the excess pushing forces are working in synergy with the expanding airflow (this synergy of pushing and blowing is often called jetting). The pushing force extends far, because part is taken by the air propelling forces, the latter increasing further in the duct and finally taking over. The gain in length of a factor of 2 could be explained by a theoretical model. This was the basis for a patent in 1987 [5], also supported by the fact that you need a certain cable stiffness to push the cable, see Fig. 7a.

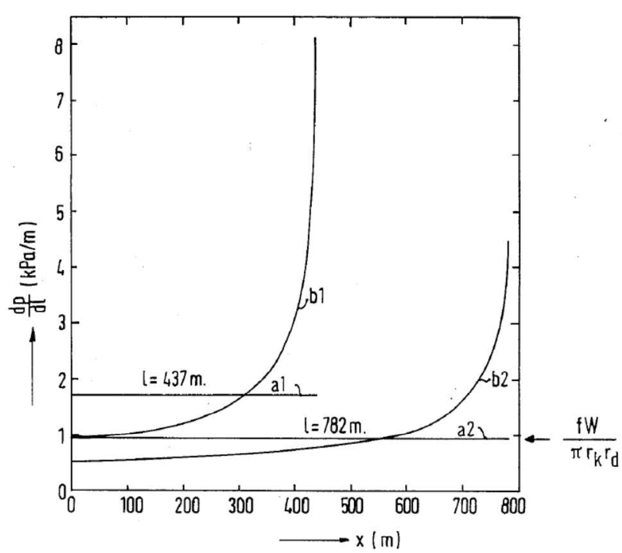

Figure 7a. Picture from European Patent EP 029037 [5]

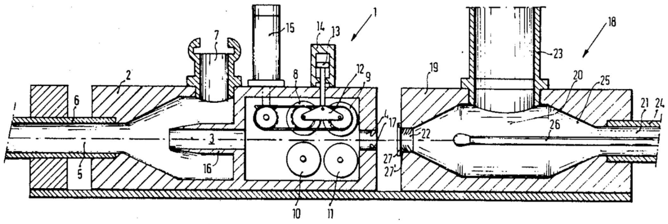

Figure 7b. Picture from European Patent EP 029037 [5]

Figure 8. First prototype of cable blowing machine in operation

The rest is history. A prototype blowing machine was made (with mechanical drive), see Fig. 7b and 8. After testing in the field the installation crew did not want to return it and ordered 4 more machines to try tandem operation. This also worked (the 2.1 km could be installed by 4 machines in tandem, see Fig. 9, without sync issues), machines also kept and 30 more machines ordered. After that all optical cable installation in The Netherlands was done by blowing (blowing length 700 m, but for flawless blowing 4 machines operated in tandem taking 525 m each) within 4 months after the first manual trial [6,7]. Installation crews, motivated to compete for a daily installation record, reached up to 12.6 km in one day. Visitors from other countries were amazed. Soon an exclusive license was given to the Swiss company Plumettaz SA, introducing the technique worldwide. The first commercial machine is shown in Fig. 10 and another commercial machine, in operation, in Fig. 11. Today, blowing lengths are much longer (see further) and buffering techniques are used more than tandem operation of blowing machines, but still (partly) deploying several machines tandem can be an economical choice [8].

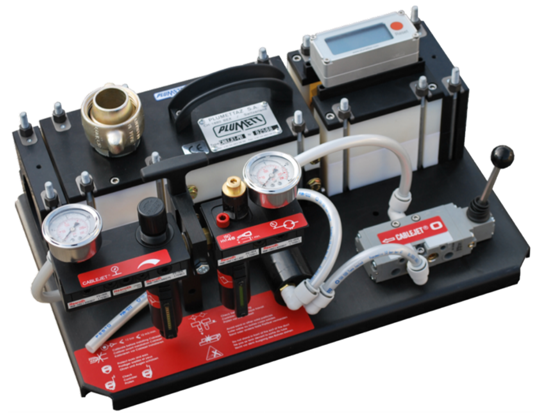

Figure 10. First commercial cable blowing machine

Figure 11. Another commercial cable blowing machine in operation

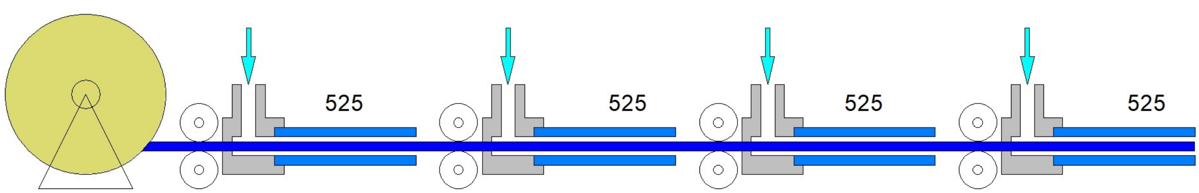

Figure 9. Installation of optical cables (full 2100 m) into ducts by blowing in The Netherlands in 1987

2. Situation Today

Not only the fact that long cable lengths can be installed by blowing, also other advantages made this technique conquering the world as the most used technique today. Installation is easy, one-step, no need to install a winch line first. Furthermore, installation can be done all from one side of the duct, for labor, equipment and cable drum. Also, the forces on the cable are low, an order of magnitude less than for pulling. Finally, it is now easy to blow cable overlength into intermediate handholes.

2.1 Microduct Cabling

10 years after the invention of cable blowing, it was also used to install microduct cables into microducts, the latter similar to the "bores" used for blown fiber. However, the microduct cables were quite stiff. The first use was with micro copper quad cables, for new installations of the copper access network, prepared for later replacement with micro optical cables [9]. The first generation of these micro optical cables, so-called microduct cables, contained steel tubes, to cope with thermal expansion of these small cables.

Later non-metallic microduct cables were used [10]. This was made possible due to improved cable constructions and optical fibers with better micro- and macro-bending properties. The microducts were blown in loose bundles (containing easily up to 10 microducts) into larger ducts (the free space offering excellent mechanical protection), see Fig. 12 and 13. After the bundle of microducts has been installed it is possible to make a mid-span branch at any time and any location using a dividable Y-connector, see Fig. 14, with one (or more) of the microducts coupled by push/pull-connectors to branch microducts [9]. In this way, optical cables can be blown through intricate routes, without the need to make a splice in the optical fibers.

Figure 12. Blowing loose bundle of microducts into a larger duct

Advantages of microduct cabling are 1) the ability to only install the fibers needed at the time of installation (pay as you grow), 2) serial upgradeability (extend networks later by coupling new ducts and microducts), 3) parallel upgradeability (later new customers can be connected any place any time) and 4) building redundant connections by clever use of empty microducts (left and right "woven into each other", empty microducts beyond the branch used for other direction, see city ring and half rings in Fig. 15).

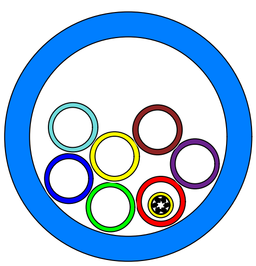

Figure 13. Cross sectional view of duct with loose bundle of microducts

Figure 14. Y-connector branch in microduct networks

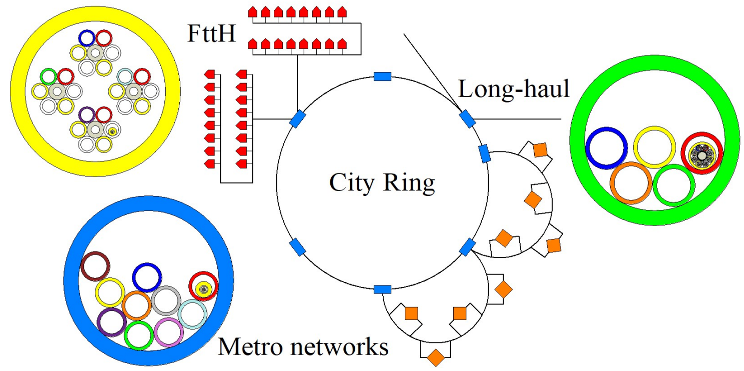

Figure 15. Schematic view of access network, with redundant primary ring and redundant secondary half-rings for business customers

Nowadays, with the microduct technology, it is possible to put in a small trailer, a van or a pick-up truck:

- Drum of FO Cables
- Drum stands
- Compressor
- Blowing machines
- Box of Tools and accessories

A team of two people is sufficient to reach over 6 km per day.

At present also tight bundles of microducts are used [11], often buried directly into the ground without a larger surrounding duct, see Fig. 16, more in line with the original "bores" of the blown fibers. Also very small cables became available, almost closing the gap between microduct cables and blown fibers. Care shall be taken that the filling ratio is not too high with these tight bundled microducts, as micro-undulations might limit the blowing length, depending on how the bundles were buried [11].

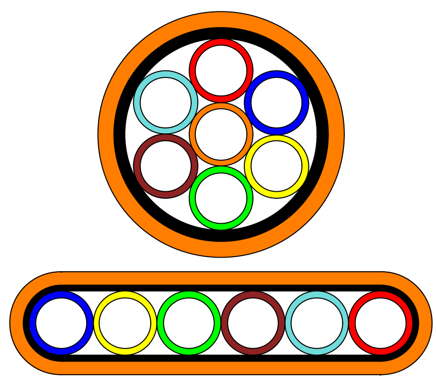

Figure 16. Cross sectional view of examples of tight-bundled of microducts

2.2 Override Blowing

It is also possible to override existing cables by blowing cables or microducts on top of them [12,13]. This is done with the help of dividable Y-connectors, see Fig. 17. The latter leads to significant cost savings when upgrading cable routes without the need to dig again. As blowing lengths are not always long in this case, it is often more economic to blow short lengths of microducts and couple them to longer routes by simple push/pull connections (no splice). In the microducts then long cable lengths can be blown avoiding, or at least limiting, buffering of the cable. Example: the first cables blown in the Netherlands (in the mentioned 32/26 mm ducts) had a diameter of 9.7 mm and contained 6 fibers. At that time (in the "eighties") it was stated that the duct was fully used (recommended max filling diameter ratio of ~1/3). Many years later, an upgrade was needed. Recommended (diameter) max filling ratio had grown to 80% in this time, so the old limit was no longer there. This gave space to extend the duct capacity by overriding with cables or with microducts with optical cables. Although it was only possible to blow short lengths (about 200 m) of 2 microducts 10/8 mm (for the optical cables the blowing length was even shorter), they could simply be coupled to longer routes. In this way a real duct upgrade was made (in the old ducts the blowing length was so poor because besides a non-favorable geometry the paraffin oil, used as a lubricant when the cables were blown in, had become tacky). Better materials and lubricants made possible cable blowing lengths of 1500-2000 m in the microducts (compare to 700 m in 1987), even though the filling ratio was much higher, and the cables contained 96 fibers each, an upgrade by 3200%!

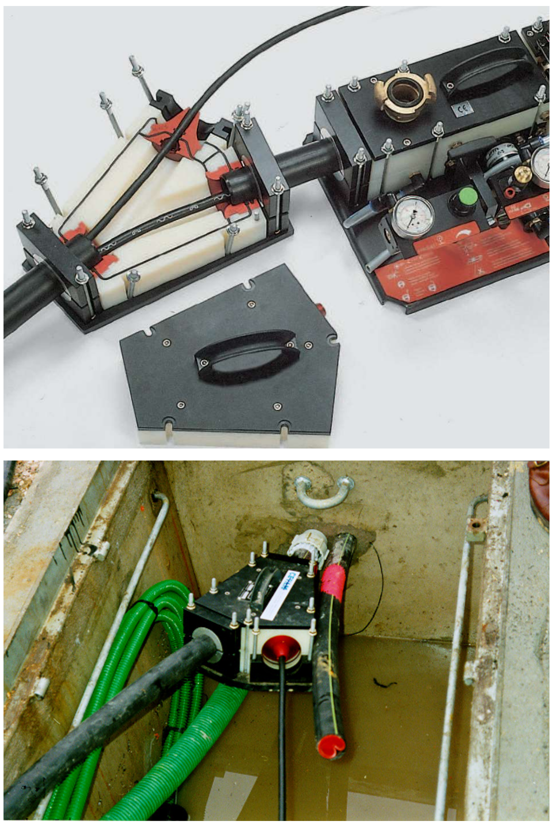

Figure 17. Y-Connector, to override cables or microducts in ducts occupied with previously installed cables

2.3 Cable Blowing Records

As mentioned in the previous section better materials and lubricants have led to increased cable blowing lengths. Not only that, also the construction and quality of (micro)duct and cable contributed. First, the cables, usually not with metal shields anymore, became less heavy. In addition, the cable bending memory was minimized, especially important for high cable filling ratio. It was also important that micro undulations of cable and (micro)duct were minimized. Improvements on lubrication were made, by using the right lubrication method and by using a Cable Lubricator [14], see e.g. Fig. 18, top. Other improvements are the use of Compressed Air Coolers and Sonic Heads (Fig. 18, bottom).

Figure 18. Example of Cable Lubricator (top) and Sonic Head (bottom)

As the first cables blown reached maximum 700 m per shot, today we reach much longer distances (also with higher filling ratio). A big step was made in 2004 [10], where for the CERN Large Hadron Collider project many parallel microduct cables had to be blown, from above ground down into the 28 km long tunnel to connect the individual dipole and quadrupole superconducting magnets (placed every 50 m), see Fig. 19. Because of that it was required that the maximum cable length of 2.5 km could be blown in one shot. Later, in the same project, a maximum blowing length of even 3.6 km was reached. Today the record for a single blow is 5.3 km in a single blow, reached in the mountains of Switzerland [15], see Fig. 20.

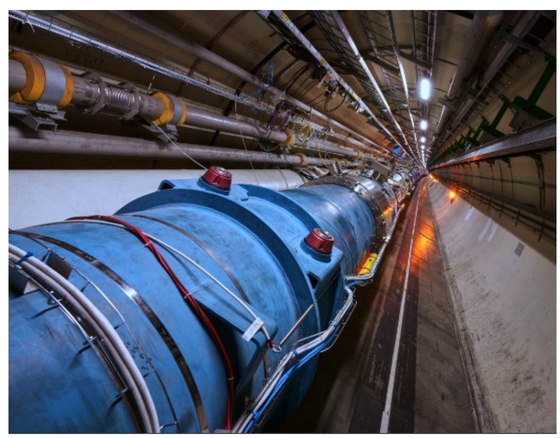

Figure 19. Large Hadron Collider at CERN

Figure 20. Blowing record (5.3 km) in Swiss mountains

2.4 Today's Benefits

Today's benefits of cable blowing summarized:

- Faster to install (80 -150 m/min & about 10 km per day)
- Less people needed (team of 3 people can install 8-12 km per day) – Easier to manage, quick answer to the market
- Less machinery (1 small blowing equipment and compressor can replace multiple winches and multiple people) = Much easier to handle, and quick start = Better ROI
- Safer for the Fiber Optical Cable (Low stresses during cable installation) = Longer life
- Thanks to the technique of blowing optical cables have been made lighter over time, and new constructions/design have been built to make them easier to install and with considerable economic advantages for the Telecom industry
- Less disturbance during installation / keep the roads opened
- Faster to deploy a network
- Taking advantage of existing HDPE duct in the local infrastructure
- Possible to override, generating significant savings because you don't have to dig and install another duct
- Easier to create cable overlength in handholes
- Easier to maintain. When it is a matter of maintenance or cable replacement, there is no better way than blowing to refurbish quickly a damaged network

2.5 Cable Blowing Limits

Where in the beginning it was thought that only special cables can be blown, today we know that all kind of cables can be blown, most of them originally meant (and still specified) for pulling. However, as already mentioned the blowing technique led to lower stresses on the cable during installation, allowing for less heavy cable construction / design, easier to install. Cables with different fiber-counts are blown today, ranging from 1 to 6912. To make the latter cable compact enough to be blown into traditional ducts special techniques are used, like rollable fiber ribbons [16], bend insensitive fibers and miniaturization of the fibers (fiber core still 125 µm, but coating reduced from 250 µm to 200 µm, recently even 180 µm). Even large copper quad telecom cables (150x4) were blown into 63/50 mm ducts, where a record weight of 3.8 tons (2x1.9 tons) of 35 mm cable was blown (in tandem) [17], see Fig. 21. The limits of cable blowing are defined by compressor size and, most importantly, safety. The maximum size of a duct (usually HDPE) recommended is 63/50 mm (2 inch).

Figure 21. Blowing record 2x1.9 tons of 35 mm copper telecom cable

2.6 Cable Blowing Spin-Off with Water

Instead of air, also water can be used as a propelling fluid, called floating. The principles are the same as with blowing, but an additional benefit is buoyancy, which reduces the effective weight and hence gravity friction. This allows even longer installation lengths. The record today of 12.4 km in one flush, again reached in Switzerland, was done with a standard optical cable [18] floated with help of a triplex Jet, see Fig. 22. This was reached easily, the cable arrived almost immediately after the water, indicating that this cable could have flown further when the duct had been longer [19]. When using buoyancy balanced cables, and/or "tuned" brine as propelling liquid even much longer lengths are possible. Only one small friction contribution then remains (which can also be made small when reducing sharp bends and using flexible cables): friction from cable stiffness in bends and undulations. Therefore, expectations are that in the future still much longer floating lengths can be reached, why not 100 km.

Another benefit of water above air is its higher viscosity, allowing use of larger ducts with relatively small pumps and still reaching high enough pressure [20]. This makes the technique also useful to install medium and high-voltage energy cables [21]. Floating has been successfully done in ducts up to 125/102 mm and it is expected that even one or two sizes larger is still possible when boundary conditions are good. Note that the Floating technique is also used to install bare optical fibers into very small steel tubes with an inner diameter of a few mm using water of high pressure, see Fig. 23 [20].

Figure 22. Triplex Jet for Floating record of 12.4 km cable

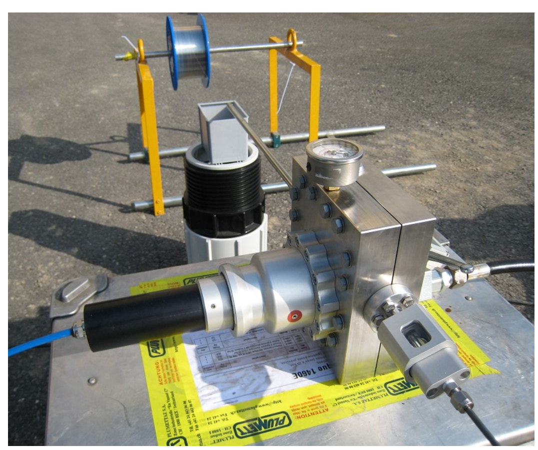

Figure 23. High pressure Jet for Floating bare fibers into micro steel tubes

When still larger cables and ducts are used, it is necessary to use a pig in front of the cable to limit the flow. This technique is called WaterPushPulling [21]. Drawback is the fact that there is no distributed drag force anymore from high-speed fluid flow to propel the cable. All force from the water pressure is now concentrated on the pig as a pulling force. This means that the capstan effect is back and the installation length will not be so spectacular anymore. However, as there is still the benefit from buoyancy, and there is a combined action of pushing and pulling and because the trajectories are usually rather straight, still long installations lengths have been reached, up to 3.3 km so far. In addition, after a cable has been installed by WaterPushPulling another spectacular technique, called FreeFloating, can be used to transport the cable to any location wished, lose from the machine [21]. We are still on the move!

Figure 24. WaterPushPulling energy cables

3. Conclusions

A review is given of the history of the cable blowing revolution, as a replacement of the traditional cable pulling technique. It arose from serious installation problems in The Netherlands. The technique, developed by the Netherlands PTT, was soon licensed to the Swiss company Plumettaz SA, marketing the technique worldwide. The advantages are so clear that blowing has become the standard method for installation of optical cables into ducts. Improvement of cables, ducts and lubrication made the blowing length increase and the fiber count in a duct rise. The blowing technique was also the trigger to develop the microduct cabling technology. The benefits are manifold and several variants are used. Today the trend is higher-fiber counts and the sky seems to be the limit. Several spin-off techniques can be recognized, e.g. replacing airflow by water flow. Now all sizes of cable can be installed by fluid flow, from bare optical fibers, via microduct and standard optical cables, to high voltage energy cables. New developments continue to challenge cable installation technology.

4. Acknowledgments

We are grateful to many persons involved in the development and use of the cable blowing technique, too many to mention by individual names. In the early days, the development of the cable blowing technique was made possible by pioneering tests done at Radio Kootwijk (NL) and colleagues of PTT DKRV and PTT dr Neher Laboratorium were of great help there. In the subsequent development of microduct cabling a huge number of tests was done at NKF (later Draka) at their cable plant in Delfzijl, and both persons from there and from the Draka Gouda offices were doing a great job. Interactions with cable installers, even other cable manufacturers, and people from Plumettaz further contributed to make the blowing technique mature worldwide. At Plumettaz also pioneering work was done with spin-offs of cable blowing, also with use of water, for the whole range from bare optical fibers to high voltage energy cables. One key person, who unfortunately passed away, has to be mentioned here because he was the enthusiastic booster for all of said techniques: Gerard Plumettaz.

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Michael van Moppes received a M.Sc. degree in Material Science and Engineering from Delft University of Technology in 1988. After various function's within the aerospace, aluminium and offshore industry he joined Plumettaz b.v. (NL) in 1998 as Area Sales Manager responsible for Northern and Western Europe. Plumettaz b.v. is a subsidiary from Plumettaz SA, Bex (CH), the world leader in the design and manufacturing of cable laying equipment. From 2005 he has been responsible for APAC region and in 2009 became Vice-General Manager at Plumettaz Project Equipment (Shanghai) Co., Ltd. In 2011 he became General Manager at Plumettaz Singapore Pte. Ltd., and December 2020 he joined H.M.S. Machines, Gouda, The Netherlands as Application Manager Plumettaz Group.

Vitor Gonçalves completed graduate studies in business and Marketing. In 2002 he followed the Business and Management school IFCAM. In 2008 he received the Swiss Federal diploma MarKom and in 2015 the Diploma of Sales Manager. He joined Plumettaz SA, Route de la Gribannaz, CH-1880 Bex (CH) since 1997 in different positions, Sales and Marketing department in 2001 and became ASM in 2006 for Middle, and Southern Africa and LATAM. In 2010 he moved to the USA as Marketing and Sales Manager for Plumettaz Incorp USA and returned to Switzerland in 2012 as ASM for key EU Countries + Americas. In 2021 he became Senior Business Development Manager (Global) for Energy and related Tailor Made Products.