Installing Sensor Fibers or Cables for Power Cables

W. Griffioen, V. Chaves
Plumettaz S.A., Department BT / R&D
Bex, Vaud, Switzerland
+31-6-20209745 · willem.griffioen@plumettaz.com

Abstract
Distributive Temperature Sensing (DTS) with optical fibers is a way to optimize the current rating of power cables. Today, power cables often contain optical fibers or microducts to install them, but a lot of installed cables are without those fibers. When power cables are in ducts, there is place to override them with optical cables. But the wedge between cable and duct makes this difficult. In this paper a method is described where first a microduct is floated in, and later the optical cable is installed. Special tricks are used for the installation, like "out of wedge" installation, the use of a "JetPig" to propel the front end of the cable and sinking the optical cable close to the power cable after installation.

Keywords: Distributive Temperature Sensing (DTS); power cables; current rating; optical cables; optical fibers; ducts; installation; override; jetting; floating.

1. Introduction
To optimize the current rating in (MV/HV) power cables, there is a need to measure the temperature along the cables. Distributed Temperature Sensing (DTS) with optical fibers is a technique used for this. Here the temperature distribution is measured by e.g. Raman-, Brillouin- or Raleigh- backscattering or Bragg-grating reflection.

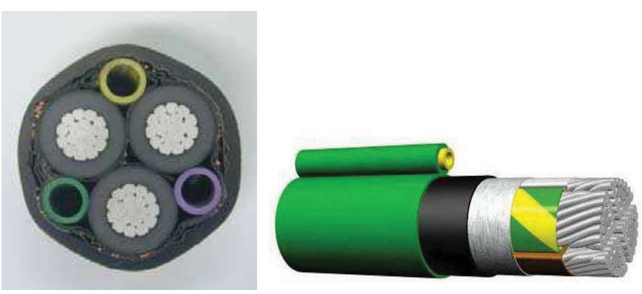

Figure 1. Examples of power cables with microducts

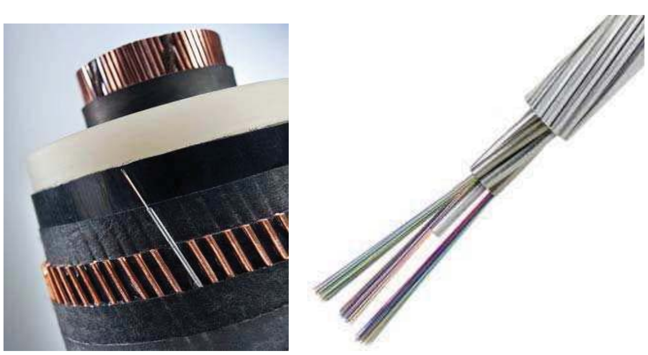

Figure 2. Examples of power cables with optical fibers

Today, power cables are often produced with optical fibers, or with microducts in which optical cables can be installed later. In Figure 1 examples of power cables with stranded and straight microducts are shown. Optical cables can be installed into the microducts by jetting (blowing) or floating [1]. When power cables are produced with optical fibers, the fibers usually are installed in steeltubes. In Figure 2 an example is given of a power cable and of an OPGW (Optical Power Ground Wire) with optical fibers in steeltubes.

It is, in principle, also possible to install the optical fibres into the steeltube at a later stage, reducing the number of splices. For this the fibers are floated with high pressure into the steeltubes, a technique known from installing sensor fibers for pipe monitoring. In Figure 3 the equipment for floating bare fibers into steeltubes is shown [2].

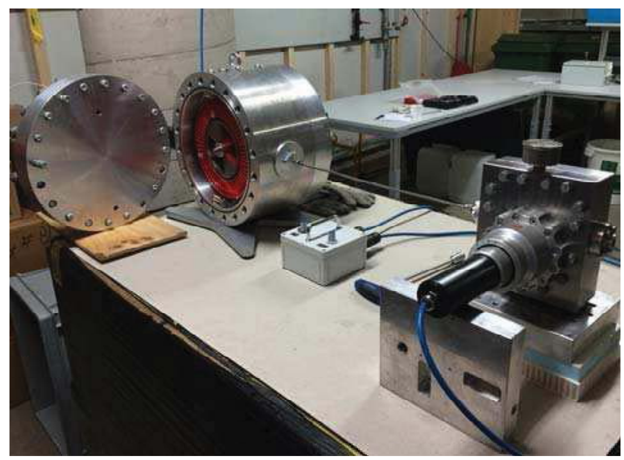

Figure 3. Equipment to float bare optical fibers into steeltubes

But, a lot of power cables have been installed without such fibers. In case the power cables are situated in ducts, there is place to override them with optical cables. But, power cable and duct surface are often of high friction, there is a lot of dirt and water inside and there is a strong wedging effect that makes installation of the optical cable difficult. In [3] a formula was derived to calculate the wedge factor f_{wedge} which is the factor with which the coefficient of friction is effectively multiplied:

$$f_{wedge} = \sqrt{\frac{(D_c + D_{c2})(D_d - D_{c2})}{D_{c2}(D_d - D_c - D_{c2})}} \qquad (1)$$

Here D_d is the internal diameter of the duct, D_c the diameter of the resident (power) cable and D_{c2} the diameter of the new (optical) cable which is installed by overriding (see Figure 4).

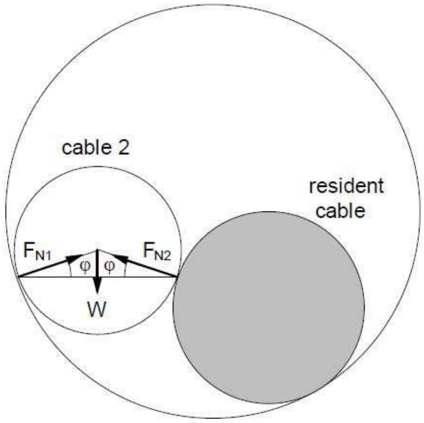

Figure 4. Forces acting on a wedged cable

In Switzerland a trial was done to install a 5 mm optical sensor cable into a duct with 150 mm internal diameter, occupied with a 91 mm High Voltage (HV) cable over a length of 820 m (the target distance). Here it was tried to sucking in the optical cable by using a 40000 m^3/hour (air) "Saugbagger" [4] (see Figure 5). Unfortunately, a length of only 60 m was reached.

Figure 5. Saugbagger trial to suck in optical cable into duct with power cable

In this paper it is analyzed why override of a power cable in a duct with an optical cable by the suction method with the "Saugbagger" is not working, not even when the optical cable is sucked in using water (which also would bring the risk of moving the power cable). An alternative method is proposed and analyzed to install the optical cable over the power cable.

2. Analysis of Suction Trial

2.1 Air Suction

The flowrate Φ through the pipe with a power cable and the flow velocity v can be approximated by Blasius´ law [2,5]:

$$\Phi = 2.3\frac{\left(D_d^2 - D_c^2\right)D_h^{5/7}}{\mu^{1/7}\rho^{3/7}}\left(\frac{dp}{dx}\right)^{4/7} \qquad D_h = D_d - D_c \qquad (2)$$

$$v = 2.9\frac{D_h^{5/7}}{\mu^{1/7}\rho^{3/7}}\left(\frac{dp}{dx}\right)^{4/7} \qquad (3)$$

Here μ is the dynamic viscosity (1.8×10^{-5} Pas for air) and ρ the density of the flowing fluid (1.3 kg/m^3 for air), dp/dx the pressure gradient over the pipe and D_h the hydraulic diameter of the pipe with cable (approximated as D_d-D_c [3,6]). The flowing fluid (air, a gas) is compressible. For vacuum (absolute pressure zero) at the suction side the (absolute) pressure p and the pressure gradient dp/dx follow as a function of the location x in the pipe [5]:

$$\frac{dp}{dx} = \frac{p_i}{2l\sqrt{1-\frac{x}{l}}} \qquad p = p_i\sqrt{1-\frac{x}{l}} \qquad (4)$$

Here p_i is the (absolute) pressure at the pipe entry (1 bar), at x=0, and the pressure at the exit end of the pipe, at x=l, is zero. Note that the pressure gradient at the pipe entry is half of what it would be when incompressible fluids (liquids, e.g. water) are used. From (2), (3) and (4) the pipe flow and velocity follow. For atmospheric pressure at the pipe entry and vacuum at the pipe exit, for a pipe of 820 m long, with internal diameter of 150 mm, filled with a power cable with diameter of 91 mm, a flow velocity of 17 m/s and flow rate of 700 m^3/hour follow at the entry of the pipe (i.e. the maximum flowrate of the Saugbagger is by far not used).

Question is now whether this flow is sufficient to propel the new sensor cable in the pipe with HV cable. The air propelling forces follow from [5]:

$$\frac{dF_{blow}}{dx} = \frac{\pi}{4}D_h D_{c2}\frac{dp}{dx} \qquad (5)$$

Here D_{c2} is the diameter of the new FO sensor cable. Said air propelling forces need to be higher than the friction forces, given by [3,5]:

$$\frac{\pi}{4}D_h D_{c2}\frac{dp}{dx} > f_{wedge} f W \qquad (6)$$

Here f is the coefficient of friction (COF) between sensor cable and pipe / power cable and W the weight of the sensor cable per unit of length, for a 5 mm FO cable about 0.25 N/m (density 1.27 g/cm^3). For a 5 mm sensor cable in a 150 mm inner diameter pipe with 91 mm power cable the wedge factor is 7.18, a big effect!

The air propelling forces are smallest at the cable entry point at x=0, where the (absolute) air pressure is 1 bar. For a 820 m long pipe the pressure gradient is equal here to 61 Pa/m. From (6) now it follows that the cable will only go with the flow when the COF is smaller than 0.008. Such values have never been obtained (without wedge it would go for 0.057, which is still a lower COF value than ever reported for cable in pipe installation). So, there is an explanation for the fact that installation did not work this way!

The effect of the parachute at the end was not yet included. For the force F a parachute can generate, the following general formula for flowing around objects is used [6]:

$$F = \frac{1}{2} A \rho v^2 C_d \qquad (7)$$

Here A is the cross-sectional area (perpendicular to flow) of the object and C_d the drag coefficient. The latter is, for Reynold numbers larger than 2×10^5, about 0.18 for a sphere and 1.2 for parachutes. The flow velocity of 17 m/s (Reynold number 7.25×10^4) will generate a force of 0.62 N (for Reynold numbers larger than 2×10^5, so the force might be two or three times as large) on a parachute with diameter of 59 mm (maximum size in the pipe with HV cable). For a straight pipe with HV cable and a COF of 0.1, this would be just enough to pull 5 m (or 2 or 3 times as large) of OF sensor cable (right part of equation (6) used).

For the installation distance that can be reached both the effect of parachute and air propelling forces along the cable need to be taken into account, plus some force due to pushing in (pushing cannot be done very far, because buckling easily occurs for this small flexible sensor cable in the large pipe). On the other hand: the previous calculation was for a straight pipe and a straight cable, perfectly at the bottom of the pipe. In practice also bends and undulations are present, and the HV cable can be "snaked" in the pipe when there is cable overlength due expansion resulting from increased cable temperature. There is a risk that the FO cable winds around the HV cable, especially in bends.

As a conclusion, theory explains why 820 m could not be installed, and the result of 60 m was even a "lucky shot".

2.2 Water Suction

What happens when the previously described method is used when the pipe is entirely filled with water? Both density (now 1000 kg/m^3) and viscosity (now 1.1×10^3 Pas) have different values now. Moreover, the flow is incompressible now, so instead of (4) the following equations hold:

$$\frac{dp}{dx} = \frac{p_i}{l} \qquad p = p_i\left(1 - \frac{x}{l}\right) \qquad (8)$$

The pressure gradient and water propelling forces are constant now, so balancing of these forces and (gravitation) friction forces will not depend on the location in the pipe. Also the pressure gradient is twice as large as for air at the entry of the pipe. Now a flow velocity of 0.82 m/s (Reynold number 4.4×10^4) and flow rate of 33 m^3/hour follow at the entry of the pipe. Will the "Saugbagger" capacity: 40000 m^3/hour for air and 8 m^3/hour for cohesive soils be enough to reach this? Let´s assume as a best case that the answer is yes.

For equation (6) no changes occur because of the smaller flow, only the pressure gradient is twice of that of air and the effective weight of the FO sensor cable drops to 21% of its weight in air, i.e. the COF for which installation by water propelling forces works will be about 10 times higher. So, for a COF of 0.08 it will just go. This value is obtained sometimes in practice, but it is on the limit, especially for an existing pipe with power cable. Then there is also the problem that the pipe may not be straight and the power cable is "snaking". Without the wedge factor, there would be enough margin, but the wedge is simply there.

The force generated by the parachute will now be 1.1 N, only a bit higher than for air. So, here we gain a factor of about 5 (the lower effective weight of the sensor cable) and a length of 25 m could be pulled (and a factor of 2 or 3 more because of the lower Reynolds number). Together with pushing and the flow propelling forces, installation over the full length might just be possible, but only in ideal cases.

There is another note. The waterflow will also have an effect on the resident power cable. For a power cable weight of 78 N/m (light weight alumium core cable) and a COF of 0.08, the power cable would also start moving with the waterflow, not a preferred situation!

2.3 Conclusion for Suction Techniques

It has been theoretically explained while air suction only resulted in 60 m installation length. When the same technique is used with water instead of air, reaching 820 m could be possible on the limit, but every bend or contamination could kill the process. Moreover, the HV cable just about starts to move too for the favourable conditions.

3. Proposed Alternative Method

3.1 Method

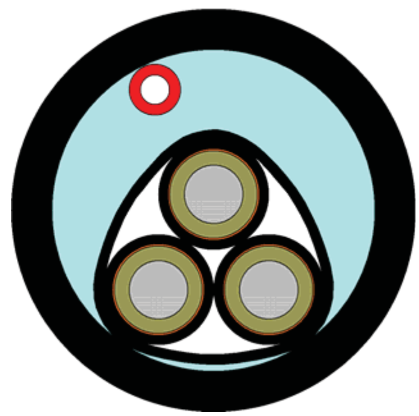

Figure 6. Microduct installed outside the wedge

In the proposed alternative method [7] wedging is avoided by using buoyancy. First the duct is filled with water. Next a microduct is installed just floating (out of the wedge between duct and power cable). When a standard HDPE microduct filled with water is used, this "just floating" condition is met. Alternatively, an empty (air) microduct is used where the uplift force is minimized by using heavier plastics. This is the case in Figure 6.

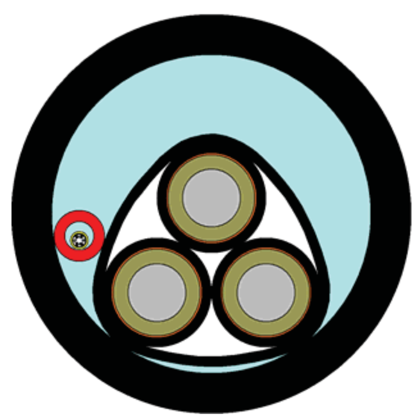

Figure 7. Microduct sunk into the wedge

Next the microduct is sunk into the wedge (close to the power cable, for optimal temperature measurement of the cable jacket), by filling it with cable and/or water (different methods exist for installing the cable into the microduct, like jetting and floating [2,5]). Different "float-and-sink" methods exist, e.g. installing standard microducts with water as propelling fluid and bringing them into position by removing the water from the duct, or by using a heavy optical cable, or by using high-salinity water, or by pulling back the microduct while leaving the cable. Alternatively, installing heavy microducts (preferably non-metallic, e.g. using additives, or using FRP armoring, also helping to protect against moving power cables during temperature variations) is done with air as propelling fluid, and simply bringing them into position by filling the microduct with water (when pulling the microduct back after installation of the cable, it is no problem to use microducts with metallic shields). A trial with this method is still planned.

In Figure 8 an embodiment of the method for installation of the microduct is shown. Microduct 2 is installed from coiling device 4 [8] driven by pushing means 6 through guide duct 8 into a manhole 10. Here the pipe 12 with power cable 14 is accessed. The pipe end is closed by a dividable coupling 16 which allows passing through microduct 2, while guide duct 8 is coupled to it. Coupling 16 also has an entry 18 through which the pipe 12 can be filled with water. At the front end of microduct 2 the JetPig 20 is attached. A pressurized fluid (air or water) is fed into microduct 2 at the coiling device 4 side by pump 22 and exits the front end of microduct 2 via said JetPig, where the direction of the flow is reversed. The now backwards directed flow of fluid causes a forward directed force on the front end of microduct 2 which, together with the pushing at the coil side, moves the microduct 2 forwards. There is no need to flow the water inside the duct when using above described method, the pushing force to insert the microduct and the small pulling force at from the JetPig will do the job.

3.2 Analysis

An analysis is made using two examples (820 m trajectory) to illustrate under which conditions the method will work.

Example 1: The microduct is a thick-walled 12/8 mm HDPE (0.95 g/cm^3, standard) microduct that is installed with water as a propelling fluid, at a pressure of 40 bar (maximum for this microduct). The total density will be 0.97 g/cm^3, so the microduct is just floating on top (no wedge factor). The water will flow with a speed of 1.62 m/s (Reynolds number 20000, turbulent pipe flow) and a volume flow of 0.08 l/s. When the JetPig just reverses the direction of the outcoming water, the impulse change of the outcoming water (is a measure for the force) will result in a forwardly directed force of 2×1.62 m/s×0.08 kg/s = 0.26 N. In a simple way the same order of forward moving parachute force is obtained as with the heavy flow of all the water in the pipe in Section 2.2! In Figure 9 it can be seen that for a JetPig force of 0.26 N and for a coefficient of friction of 0.1 the microduct can just be installed with a pushing force of 10 N. Note that pushing harder will not make much sense in this relatively large duct: the microduct will only buckle. A higher force can be made when using small nozzles, increasing the outflow speed (but taking also a bit from the pressure drop over the duct). When the total cross-sectional area of the JetPig backwards directed nozzles is 20 times less than the cross-sectional area of the internal microduct (i.e. 2.5 mm^2) the force on the JetPig will be 21×1.62 m/s×0.08 kg/s = 2.72 N. Now the JetPig alone almost can pull the microduct, as can be seen in Figure 9.

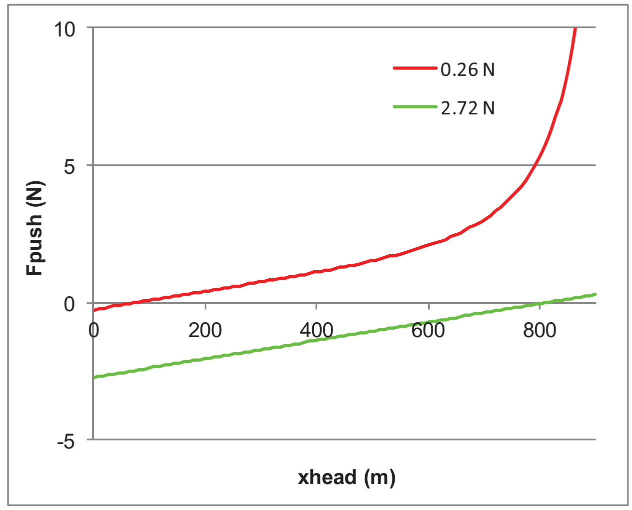

Figure 9. Pushing force for Example 1 for a coefficient of friction of 0.1 for JetPig force 0.26 and 2.72 N, respectively. Calculation done with JetPlanner [9]

Example 2: The microduct is a thick-walled 12/8 mm HDPE heavy (1.75 g/cm^3, with non-metallic additives or metallic shield) microduct that is installed with air as a propelling fluid, at a pressure of 16 bar. The total density will be again 0.97 g/cm^3. The air will flow with a speed of 105 m/s (Reynolds number 55000, turbulent pipe flow) and a volume flow of 0.32 m^3/min. The force of the parachute pig now depends on how the bubble flow interacts with the water in the pipe and is not easy to calculate (but the high speed air probably generates a large force). Trial and error needed. Note that with the JetPig in free air already a force of 2-3 N was reached, see Section 3.3.

3.3 Tests with JetPig

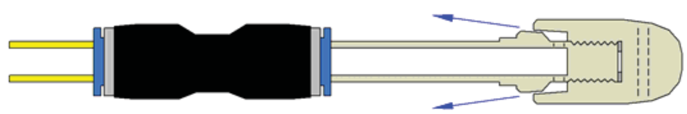

Figure 10. Drawing of JetPig on microduct end

In order to evaluate the force the JetPig can generate, tests were done with a proto-type, see Figure 10. Two types of 12/8 mm microducts were made, with densities of 1.3 and 0.99 g/cm^3, respectively, the latter used in the tests. First tests were done with 25 m of microduct with 8 bar water pressure. When the JetPig was not fully "closed" a pulling force of 1-1.5 N was measured, while the flow was 14.8 l/min (3 bar over the microduct). "Closing" the JetPig in 2 steps resulted in flowrates of 13.5 and 9.4 l/min (5.5 and 6.5 bar over the microduct), respectively, while the pulling force increased (!) to 2-3 N, about the same for both cases. Even though the flow decreased, the force increased because of the higher outflow speed. With 1025 m microduct and 25 bar water pressure, and the JetPig in the most "closed" position, no measurable force was found yet. Indeed, the flowrate of 4.1 l/min was not high enough. A higher pressure and/or a more "closed" JetPig is required. With air (16 bar over 1025 m microduct) also no measurable force was found, while with 25 m microduct the measured pulling force was again 2-3 N.

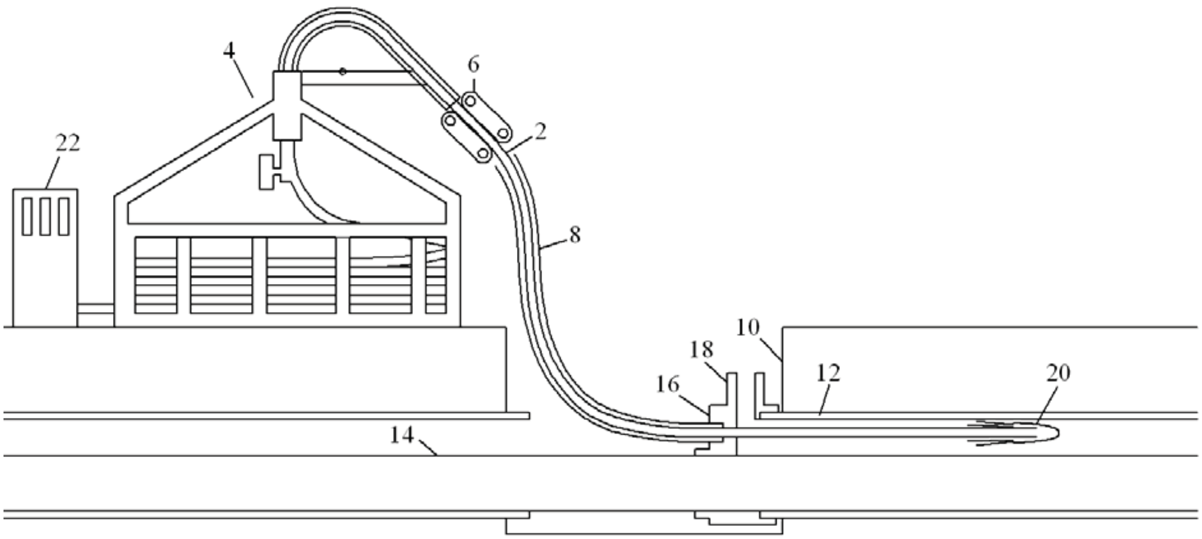

Figure 8. Schematic view of installation of the microduct

4. Conclusions

A method has been developed to insert an optical temperature sensing cable into a duct with resident power cable. First a microduct is floated in, outside the wedge between power cable and duct. Floating is assisted by pushing and at the same time pulling, using a “JetPig” which is fed through the microduct. This process has been analyzed for an 820 m long example trajectory. Tests have been done with the “JetPig”. Next the sensor cable is installed and finally the sensor cable is sunk close to the power cable.

5. Acknowledgments

Special thanks to Herbert Nyffenegger (Swiss Cable Export & Engineering), Vladimír Pelíšek, Jiri (George) Vyslouzil (Duraline), Yvan Chappuis, Jean-Luc Berod, Fabrice Abbet (Plumettaz) for their contribution to this paper.

6. References

[1] J. Fehlbaum, O. Schuepbach, V. Chaves, W. Griffioen, “Installing Cables into Continuously Coiled Ducts”, *Proc 63rd IWCS* (2014) 747-756.

[2] W. Griffioen, L. Gapany, S. Grobety, C. Gutberlet, G. Plumettaz, R. van der Sluis, A. Pijpers, Th. Weigel, “Floating Cable into Duct: Recent Developments”, *Proc 62nd IWCS* (2013) 11-20.

[3] W. Griffioen, W. Greven, T. Pothof, "A new fiber optic life for old ducts", *Proc. 51st IWCS* (2002) 244-250.

[4] http://www.gasser.ch/fileadmin/user_upload/Hoch_und_Tiefbau/Aktuelle_Projekte/TIR_2.pdf

[5] W. Griffioen, "*Installation of optical cables in ducts*", Plumettaz SA, Bex (CH) 1993 (ISBN: 90 72125 37 1).

[6] V.L. Streeter, “*Fluid dynamics*”, McGraw-Hill book company, New York 1951.

[7] Patent pending.

[8] Patent US 5911381.

[9] W. Griffioen, H.G. Nobach, G. Plumettaz, „Theory, software, testing and practice of cable in duct installation”, *Proc 55th IWCS* (2006) 357-365.

7. Authors

Willem Griffioen received his M.Sc. degree in Physics and Mathematics at Leiden University (NL) in 1980 and worked there until 1984. Then he was employed at KPN Research, Leidschendam (NL), working in the field of Outside-Plant and Installation Techniques (Telecom). He received his Ph.D. (Optical Fiber Reliability) in 1995 at Eindhoven Technical University (NL). From 1998 to 2009 he worked at Draka Comteq, Gouda (NL), on Connectivity of FttH. Currently he works at Plumettaz SA, Route de la Gribannaz 7, CH-1880 Bex (CH), willem.griffioen@plumettaz.com and is responsible for R&D of cable installation techniques (Telecom and Power).

Victor Chaves has been working at Plumettaz SA, Route de la Gribannaz 12, CH-1880 Bex (CH) since 1988. He has worked at the manufacturing department on CNC machines until 2002 and at the assembly department of cable jetting machines until 2008. Currently he works as a technical writer on documentation, as a trainer for pumps assembly (both in the company and abroad, e.g. China, India) as well as tests conductor for cable and duct characteristics. In the latter role he is operator of the DYNAF test bench