What is the Maximum Speed at which a Cable can be Blown in?

Willem Griffioen
Plumettaz SA
Bex, Vaud, Switzerland
+31-6-20209745 · willem.griffioen@plumettaz.com

Abstract
Installing optical cables in ducts by Blowing is now common practice. Sometimes this is done with very high speed. Question: what is the maximum allowable speed? Of course paying off from the reel must be well controlled. This can be observed visually, and the experienced installer will learn about its limits, not further discussed in this paper. But what happens inside the duct after a sudden stop? A crash test, where the cable is taken out of the duct afterwards, already exists. But, this test is not suitable for maximum speed. In this paper the compression wave in the cable after a sudden stop is analyzed, as well as the water hammer effect which might occur with installation by Floating. Formulas for the limiting cable speed are given. They can be programmed in intelligent Blowing machines. Exceeding the maximum duct pressure by a water hammer turns out to be irrelevant.

Keywords: Cable; optical; duct; installation; Blowing; Floating; maximum speed; crash test; sudden stop; compression wave; water hammer; intelligent Blowing machines.

1. Introduction
Optical cables are installed in ducts by Blowing [1] over more than 3 decades now. This is done with high speed, so production can be impressive (12 km per day is no exception). One can question what the limit of the speed is at which a cable can be installed. Often a speed of 60 m/min was taken for this. But, sometimes cables are installed with speeds of up to 180 m/min (and in the 90-ties even tests were done with cable speed up to 1000 m/min [2])! Of course, at a sudden cable stop the cable pay-off must also be stopped immediately, which is usually done "by hand". Sometimes it needs some time to wind the cable back onto the drum after this, but sudden stops do not occur a lot and the time this takes is usually less than the savings by using the high installation speed. Of course, care shall be taken that the cable is not damaged after a sudden stop (in the tests with cable speed up to 1000 m/min the cable was "lost"). After experience gained with this, now even large and "orthodox" Telecom Operators accept higher cable installation speeds. Fortunately, installation equipment now exists that monitors and records the cable installation speed, and besides that also the cable pushing force, blowing air pressure, air temperature and slip of the mechanical drive of the equipment [3]. There is even a possibility to set limits and safeguard these with the equipment. However, although the cable might look to be in good shape after a sudden cable stop, it cannot be seen what happened to the cable inside the duct. Was the cable maximum pulling and/or pushing force exceeded? Was there too much buckling of the cable in the duct? And is the maximum pushing force of the cable specified anyway [3]? If not specified, a crash test can be done to find the maximum pushing force. Note that, even though this test is done at high speed, it is not a sufficient indication of maximum speed, as will be argued in this paper. The maximum pulling and pushing forces the cable experiences in the duct during a sudden stop will be analyzed, as well as the resulting buckling of the cable. These forces are present over the entire length of the so far installed cable! Another effect of high speed occurs when installing the cable by Floating with water instead of Blowing with air: the water hammer when a sudden blocking of the flow occurs. As for Floating the water speed must be higher than the cable speed, this is a relevant discussion in this paper. Moreover, the theory which is developed in this paper for a sudden cable stop finds a lot of common ground with the existing theory of water hammer.

The theory has been applied for an example 96 optical fibre cable with a diameter of 6.5 mm inside a 10/8 mm microduct, representing typical microduct cabling as used in FttX / FttH. For the same cable also larger ducts (up to 40/33 mm) have been evaluated. It is found that the limiting Blowing speed is around 180 m/min (coincidentally) and that this is (surprisingly) most critical for the tightest fitting microduct. Formulas are given for the limiting cable speed in relation to the maximum pulling force (from cable specs) and the maximum pushing force (from cable crash test) of the cable and its diameter, stiffness and spring constant, as well as the duct internal diameter. This maximum can then be programmed in the intelligent jetting machines, to indicate and/or to safeguard.

The maximum speed of the water flow during Floating for which the water hammer pressure stays below 20 bar (a HDPE SDR 11 duct can easily withstand that during the installation time) is found to be about 360 m/min. Such water speeds are never reached during Floating installations, not even in the largest telecom ducts.

2. Analysis
In the following both the water hammer and the sudden cable stop will be analyzed. First the water hammer is treated, serving as a starting point for the new theory of sudden cable stops.

2.1 Analysis Water Hammer
Water hammer (or, more generally, fluid hammer, also called hydraulic shock) is a pressure surge or wave caused by a fluid (usually a liquid but sometimes also a gas) in motion when it is forced to stop or change direction suddenly (momentum change). A water hammer e.g. occurs in ducts with flowing water when a valve suddenly closes (but there are also other causes of sudden blocking possible, e.g. when a cable passes or hits a duct narrowing) somewhere downstream in a duct system, and an upstream pressure wave propagates through the duct. This pressure wave can cause major problems, like duct bursting.

When a valve in a duct is suddenly closed, the moving column of water will stop too. But, this is not occurring instantaneously for the entire column of water (which would result in infinite pressure when the valve is closed instantaneously). First the water at the valve stops and a pressure wave travels backwards, the amount of water which has stopped growing with the speed of sound c in the water, which is given by [4]:

$$c = \sqrt{\frac{K}{\rho}} \tag{1}$$

Here K is the bulk modulus of the fluid (2.2 GPa for water) and ρ the density of the fluid (1000 kg/m^3 for water). This results in a speed of sound of about 1500 m/s for water (this also indicates that for a duct of about 1 km long "closing the valve suddenly" means "closing within about 1 sec"). In a time Δt the pressure wave travels with a distance $c\Delta t$ and a mass M of the fluid has stopped then:

$$M = \frac{\pi}{4} D_d^2 \rho c \Delta t \tag{2}$$

Here D_d is the internal duct diameter. The momentum of that mass, which changed from Mv at speed v to zero at zero speed, is equal to the product of the force F and time Δt:

$$Mv = F\Delta t \tag{3}$$

The relation between the pressure p and force F at the end of the water column is given by:

$$F = \frac{\pi}{4} D_d^2 p \tag{4}$$

From (2), (3) and (4) the Joukowsky formula follows [4]:

$$p = \rho c v \tag{5}$$

Example: For a water speed of 1 m/s this would result in a pressure of 15 bar. However, the speed in a duct filled with water is lower because of expansion of the duct. A corrected speed c' can be calculated by [4]:

$$c' = \frac{c}{\sqrt{1 + \frac{K}{E}\frac{D_d}{t}}} \tag{6}$$

Here E is the Young's modulus of the duct material (1.1 Gpa for PE 100) and t the wall thickness of the duct. For a relatively thick-walled HDPE duct with SDR 11 (duct OD divided by wall thickness) the speed of sound would decrease to 23% of the speed in bulk water, and the water hammer pressure decreases proportionally.

The speed v which the water can reach in an empty duct of length L for an inlet pressure p_0 is given by Blasius [4]:

$$v = 2.9 \frac{D_d^{5/7}}{\mu^{1/7} \rho^{3/7}} \left(\frac{p}{L} \right)^{4/7} \tag{7}$$

Here μ is the dynamic viscosity (10^{-3} Pas for 20 °C water) and ρ the density (1000 kg/m^3 for 20 °C water) of the fluid.

2.2 Analysis Sudden Cable Stop

When the cable end hits an obstacle and comes to a sudden stop, it will experience a compressive axial force under which it will buckle in the duct. As the buckling "absorbs" effective cable length, not the whole cable is stopped at once. The portion of stopped and buckled cable will increase, like a wave traveling backwards. It is now calculated how much relative length of cable can be stored as a function of axial compressive force. The worst case situation is considered that the duct is fixed in its position, not moving sideward or stretching. The total "absorbed" relative (storage) length ε_s of the stopped cable length L_s is the sum of the relative axial compression ε_c of the "straight cable" and the "buckling relative storage length" ε_b:

$$\varepsilon_s = \frac{\Delta L_s}{L_s} = \varepsilon_c + \varepsilon_b \tag{8}$$

The relative axial compression ε_c is related to the (compressive) force F_c on the cable:

$$F_c = k_c \varepsilon_c \qquad k_c = \sum A_i E_i \tag{9}$$

Here k_c is the effective spring constant of the cable (A_i and E_i being the cross-sectional areas and Young´s moduli of the different cable elements). The "buckling relative storage length" ε_b is given by [5]:

$$\varepsilon_b = c_b \left(\frac{D_d - D_c}{P} \right)^2 \tag{10}$$

Here P is the period of the buckled cable inside the duct, D_c the cable diameter, D_d the inner duct diameter and c_b a geometrical constant, equal to 2.23 for a 2-dimensional sine-shaped buckling and about 4.93 (= ½π^2) for a 3-dimensional helical shaped buckling. When a straight cable is under a compressive force F_c it will buckle with buckling length b (both ends straight) [6]:

$$b = 2\pi \sqrt{\frac{B}{F_c}} \tag{11}$$

Here B is the effective stiffness of the cable. The "buckling" of the cable can be modeled when putting P equal to b. It is then found from (8), (9), (10) and (11):

$$\varepsilon_s = \left[\frac{1}{k_c} + \frac{c_b \left(D_d - D_c \right)^2}{4\pi^2 B} \right] F_c \tag{12}$$

When the cable with initial speed v_c suddenly stops, not the whole cable stops instantaneously. First the front end stops and then the amount of cable coming to a standstill grows backwards, like a sound wave, with a speed v_s given by:

$$v_s = \frac{v_c}{\varepsilon_s} \tag{13}$$

The mass M_s stopped in a time Δt is given by:

$$M_s = m_c v_s \Delta t \tag{14}$$

Here m_c is the mass of the cable per unit of length. The change of momentum $M_s v_c$ of the stopped cable is equal to $F_c \Delta t$, so with (14) it follows:

$$F_c = m_c v_s v_c \tag{15}$$

This equation looks similar to equation (5) for the water hammer. Writing out further, with (12) and (13):

$$F_c = \sqrt{\frac{m_c}{\frac{1}{k_c} + \frac{c_b \left(D_d - D_c \right)^2}{4\pi^2 B}}} \cdot v_c \tag{16}$$

One might question whether the friction of the cable in the duct has to be subtracted from F_c. Gravity friction in the cable length that has stopped in a time Δt is equal to $Wv_s\Delta t$. When subtracting this from F_c we get a squared Δt term in $F\Delta t$ which will vanish for the limit of Δt to zero. This does not change when capstan and buckling friction are added.

From (16) with (15) also the speed v_s of the "buckled cable wave" follows:

$$v_s = \sqrt{\frac{1}{m_s\left[\frac{1}{k_c} + \frac{c_b\left(D_d - D_c\right)^2}{4\pi^2 B}\right]}} \tag{17}$$

Note that here the forces are compressive, so besides not exceeding a force in the order of the maximum pulling force, the cable shall also not buckle with too small radius. The minimum bending radius R_p for sinusoidal buckling under pushing force F_c follows with [6] and is about the same for helical buckling:

$$R_p = \frac{2B}{\left(D_d - D_c\right)F_c} \tag{18}$$

From this an expression follows for the maximum force $F_{c\max}$ that characterizes this (with radius of curvature of the cable of 20 times the cable diameter D_c):

$$F_{c\max} = \frac{B}{10\left(D_d - D_c\right)D_c} \tag{19}$$

Also, this buckling creates sidewall forces between cable and duct. From (2) follows the distance $b/2$ between the cable/duct wall contacts and further with [6] the side wall force F_n for each wall contact:

$$F_n = \frac{D_d - D_c}{\pi\sqrt{B}} F_c^{3/2} \tag{20}$$

The above equations were derived for a sudden cable stop due to blocking at the front end. It is also possible that blocking occurs at the cable inlet, e.g. when a lump is present in the cable jacket. Now the cable stops from the cable inlet, and the elongation is tensile. In this case a forward "wave of cable under strain" is travelling, not under compressive but under tensile stress. Buckling storage will not occur, so formulas (16) and (17) will be with a c_b value of zero.

3. Examples

Examples for water hammer and sudden cable stops are given for a loose tube optical 96 fiber microduct cable with central GFRP strength member and with a diameter of 6.5 mm (see Figure 1), in a microduct 10/8 mm and in a larger duct, up to 40/33 mm, installed by Blowing or by Floating.

The total spring constant k for elongation is estimated (calculation) at about 3000 N per 1% strain (confirmed by measurements at Prysmian, Netherlands). For compression the contribution of the fibers will disappear (they will buckle) and also the stranded elements will be less effective, say 25%. This gives an indication for k_c for compression with a value of about 2500 N per 1% strain. In the calculations 3000 N per 1% strain is taken for both tensile and compressive (worst case) elongation.

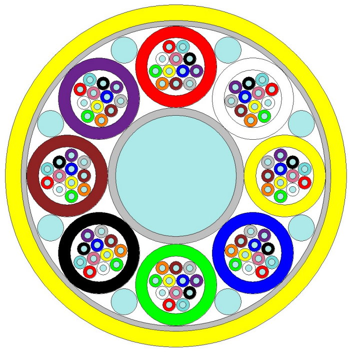

Figure 1. Example of microduct cable with 96 fibers

The total stiffness (B-value) is estimated at 0.2 Nm^2. This is a bit more than calculated from the sum of all loose elements, but less than what would follow when the position (distance from center) in the cable is taken (as compact composite). Differential slip of the individual elements in the cable will make their contribution to the stiffness much less. Bending stiffness measurements (at Draka, Netherlands) confirmed the stiffness of 0.2 Nm^2 and was used many times in evaluations of cable blowing results.

According to the cable specs the mass of the cable is 42 g/m and the maximum pulling force is 200 N for long term and 500 N for short term, the latter relevant for the sudden stop. A maximum pushing force is not given.

3.1 Example Water Hammer

For a HDPE SDR 11 duct (can easily handle short term water pressures of 20 bar) a maximum water speed is found with formula (5) and (6) of about 6 m/s, or 360 m/min. This is twice as much as the maximum speed of 180 m/min which is reached today for blowing. But for floating the cable the water speed is usually lower anyway, simply because it is not possible to let the water flow faster with the applied water pressure. The floating technique is normally used to reach longer lengths than with blowing. So, consider a duct of at least 2 km long. When a water pressure is applied of 20 bar on this duct, which is assumed to be still empty (worst case for water hammer), the water speed follows the Blasius equation (7), and ranges from 40 m/min for a 10/8 mm microduct to 110 m/min for a 40/33 mm duct, still well below the maximum speed of 360 m/min. To reach the latter water speed the 40/33 mm duct length would need to be maximum 250 m long, a length which you can install by pushing only. Even in the largest telecom ducts the speed of 360 m/min will by far not be reached.

3.2 Example Sudden Cable Stop

The force F_c at sudden stop for this cable is found with formula (16) and is given in Table 1 as a function of cable speed v_c for different (micro)ducts for sinusoidal and helical buckling. The maximum pushing "buckling" force F_{cmax}, found with formula (19), is also given, which should not be exceeded during a sudden stop (usually the maximum pushing force is lower than this "buckling" force, at least well below the specified maximum pulling force, and possibly still lower after the crash test result). The red numbers indicate exceeding of the maximum allowed force. In Table 1 the speed at which the "buckled cable wave" travels backwards is also given, just to give an idea. Note that the specified maximum puling force for this cable is 500 N and that the maximum pushing force is lower, e.g. 60% of the maximum pulling force, which is 300 N, or the maximum force found with the crash test, the one which is the lowest.

Table 1. Force F_c (N) on 6.5 mm example cable at sudden stop as function of cable speed v_c (m/min) for different ducts and for sinusoidal and helical buckling. The speed v_s of the "back traveling buckle wave" is also given

v_c (m/min)		100	180	200	300	500	F_{cmax} (N)	v_s (m/s)
All ducts	Pulling	187	337	374	561	935	/	2673
Duct size	Pushing Buckling							
10/8 mm	Sinusoidal	171	309	343	514	857	2051	2449
	Helical	157	282	314	471	785	2051	2242
12/9.8 mm	Sinusoidal	135	243	270	405	675	932	1927
	Helical	107	193	215	322	537	932	1533
16/13 mm	Sinusoidal	87	157	175	262	437	473	1249
	Helical	63	113	125	188	313	473	895
25/20 mm	Sinusoidal	46	83	92	138	231	228	659
	Helical	32	57	63	95	158	228	451
32/26 mm	Sinusoidal	32	58	65	97	162	158	464
	Helical	22	40	44	66	110	158	314
40/33 mm	Sinusoidal	24	43	48	72	120	116	344
	Helical	16	29	33	49	81	116	232

It can be seen that at the highest installation speed seen until now, 180 m/min, it only just becomes critical for the smallest microduct in which the 6.5 mm cable just fits. Not only it is surprising that the smallest duct is the most critical (not because of buckling, but because of the maximum pushing force), it is also the size of the microduct used most (it is usually aimed to get as high as possible fiber count in the limited duct space).

In Table 1 also even higher speeds are listed, not yet used, but good to know the limits for the different situations. At a speed of 500 m/min the 6.5 mm cable will buckle too much (too high F_c) for duct internal diameters up to 20 mm. For larger duct internal diameters (listed up to 40/33 mm) it is still (just) critical for sinusoidal buckling, but no problem anymore for helical buckling.

For all cases, also the critical ones, the sidewall force is still low. From formula (20) it follows that the maximum sidewall force F_n for a sudden stop of a 6.5 mm cable installed with 500 m/min in a 40/33 mm duct (the sidewall force is the largest for the largest diameter ducts) will be only 25 N for sinusoidal buckling. For cables usually a crush resistance between flat plates is specified [7], for cables as the 6.5 mm example one usually 500 or 1000 N per 100 mm. However, the buckled bent cable will not have a flat contact with the duct. So, it is better to specify a mandrel test, also mentioned in [7] but often not specified. In the test the default mandrel diameter is 25 mm, and the test is more severe than the flat plate test, so usually smaller force is specified, e.g. 2/3rd of the flat plate value [8], so the sidewall force of 25 N of the example cable is well below that. Furthermore, the bend radius of the stopped cable of this extreme example is still very large, 126 mm according to formula (18), less severe (more contact surface) than for the 25 mm bend radius of the mandrel specification, so no problems expected with the sidewall force. The buckling length (2 wall contacts for each such length) for this case is 256 mm, as is found with formula (11), so we only have one contact point in the 100 mm region of the specification, also okay. Note that the "wave speed" in the cable is larger than the sec water speed of 1500 m/s in the pulling mode and also in the pushing mode for ducts with ID up to 9.8 mm, and when the correction is made for the duct expansion even up to duct ID of 26 mm (not corrected for duct expansion due to the buckling cable, also present a bit here, but less than for the water hammer).

3.3 Example Visualized

In Figure 3 a sudden stop with blocking of water flow is visualized for a cable that is floated into a duct. In situation a) the cable is moving at certain speed, the magnitude indicated by the red arrow. It is on its way to a bad point in the duct, which is reached in situation b). Now the cable blocks and starts to buckle at its front end, as can be seen in situation c). At the same time the water flow is blocked, and the water pressure at the front end of the cable has increased because of the water hammer effect. The higher water pressure is indicated with a darker color blue. Nothing can be seen yet at the cable feeding side, the speed will still be the same and the water pressure too. Now a buckle wave in the cable is moving backward, upstream, as can be seen in position d). This goes with high speed, even faster than the water hammer travels. In the same time the blowing machine is still feeding the cable, still seeing nothing of the event. But, it will not take long. Only a little extra length fed into the duct makes a lot more extra buckles. In situation e) the buckle wave has reached the cable feeding side. Now the blowing machine stops feeding the cable, and has come to a standstill in situation f). In the sketched situation the adjusted maximum pushing force is higher than the compressive force from the sudden cable stop. The cable will buckle a little further, also shown in situation f), for which only a short extra length is fed. Unlike the buckle wave from the sudden stop, which sees the same compressive force over the entire stopped length, the buckles from the excess pushing force soon become the same as from the sudden stop when further away from the cable feeding side, because of friction of pushing the buckled cable (this effect is described e.g. in [1], [2] and [6]). From this it is understood that the compressive force from the sudden cable stop is not added to the adjusted maximum pushing force. A little later also the water hammer wave reaches the cable feeding side.

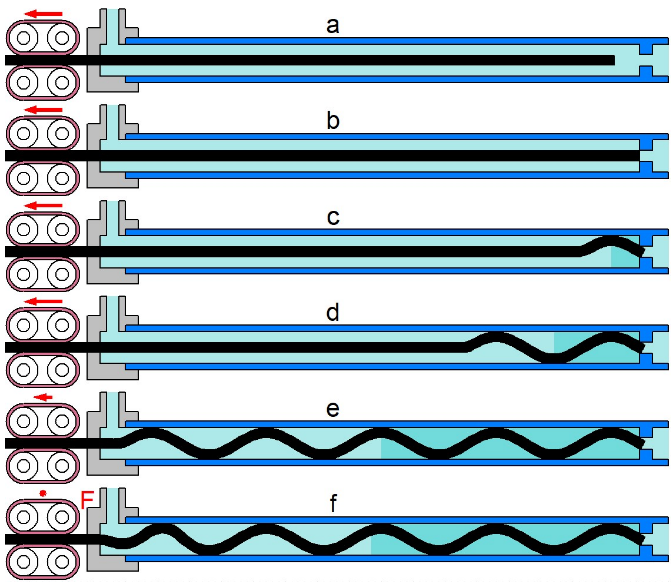

Figure 2. Example visualized, see text

4. Crash Test

A crash test (see Figure 3) before installing the cable will give some guidance to limit e.g. the pushing force on the cable [3]. But, the extremely high installation speeds are usually not reached during such a short length crash test. And if the test length was long enough such that the maximum speed was really reached, the pushing force would have been almost zero (according to the laws of Newton the cable would still accelerate when a force is applied; the only force applied is to compensate the friction of the cable in the short piece of duct, which is negligible on the short length). Only after the cable comes to a standstill the (adjusted) maximum pushing force is reached (this is also characteristic for most motors on blowing equipment).

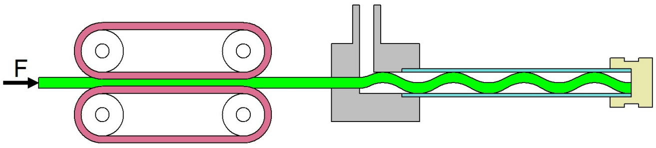

Figure 3. Crash test with buckling of cable in duct

Moreover, there are situations where high cable speed is caused by the airflow rather than by the mechanical drive, especially in relatively large ducts (duct internal diameter much larger than cable diameter). In the latter case usually the maximum pushing force will be low, because the cable will easily buckle. And low pushing force usually also means low maximum speed (again characteristic for blowing equipment). But, in case of excess airflow drag forces, after enough cable length has been installed to build up high cumulative drag forces, high cable speeds may be the result (even "pulling" the cable through the mechanical drive of the blowing equipment). So, with a short length crash test no distinguish can be made between inertia forces and real pushing forces, in fact only the latter is measured (and that is the aim of the crash test).

Note that forces in the cable due to a sudden stop will be present over the entire length of the so far installed cable. Also note that the compressive force in the cable due to a sudden stop is not added to the pushing force of the machine, see the visualized example of Figure 2. The increase of the pushing force due to stopping of the drive only starts when the compressive wave has already arrived. So, only the adjusted maximum pushing force will be reached, the compressive wave no longer contributing. In case the adjusted maximum pushing force is lower than that of the compressive wave, the pushing force will not increase any further after the wave arrived.

5. How to Check?

How to check the allowed axial forces (and from that a maximum cable speed)? The maximum pulling force can be obtained from the cable specification, for the example cable 500 N for short term exposure (the relevant one). The pushing force is usually not specified, but when nothing is known e.g. 60% of the max pulling force can be taken, 300 N in the case of the example cable. But, it is better to take the maximum pushing force from a crash test before the cable installation is done. The larger the duct, the lower the value that is found in this test, see formula (19). Taking the smallest of the two, the 300 N pushing force or the theoretical values from formula (19), the maximum speed can be reduced using (the inverse of) formula (16), for pushing selecting the worst case sinusoidal buckling c_b value of 2.23 and for pulling a c_b value of zero (and here use the max 500 N max pulling force). Such a calculation can be done with today's intelligent blowing machines, where also a safeguard maximum speed value can be set, shutting off the machine (or decreasing the speed) once the limiting value is reached.

6. Intelligent Blowing Machines

Figure 4. Examples of intelligent blowing machines

Examples of intelligent blowing machines are shown in Figure 4. Note that non-intelligent machines, where the adjusted maximum pushing force is set after the crash test (by pneumatic pressure or electric current or voltage), often run with low cable speed (due to the motor characteristics). This is especially true for relatively small cables. Intelligent machines, however, may correct e.g. the pneumatic pressure for the cable speed, and can run at any speed (as long as within the limits as given in this paper). Of course, the intelligent machine's response time shall be fast enough to really guarantee the adjusted maximum pushing force, electronically and mechanically (inertia of mechanical drive).

7. Conclusions

It is found that the highest speed of 180 m/min seen so far for Blowing optical cables into ducts is still just (just not for sinusoidal buckling in, surprisingly, the smallest 10/8 mm microduct) within the limits where no out of spec axial forces are generated into the cable at a sudden cable stop, at least for a typical 6.5 mm loose tube example cable. For higher speeds, the no-go area extends also to larger duct diameters, but only for higher speeds than 500 m/min (much faster than ever reached) also the larger ducts give problems. For cables with less max pulling force or less compressive force resistance the critical situation might be reached at lower cable speeds. A theory is given where the max cable speed follows from cable and duct parameters, while the maximum pushing force might be determined by a crash test. This might be programmed into Intelligent Blowing equipment, where the maximum speed follows and the machine can be safeguarded with that. Water speeds during Floating the cable into the duct will never give rise to water hammer effects (which would destroy the duct), at least not for duct sizes up to 40/33 mm.

8. References

[1] W. Griffioen, "A new installation method for fibre optic cables in conduits", *Proc. 37th IWCS* (1988) 172-178.

[2] W. Griffioen, G.J. Prins, "A radically new, ultra-high-speed method for the installation of cables in ducts", *Proc. 40th IWCS* (1991) 758.

[3] W. Griffioen, L. Saint-Raymond, D. Plumettaz, C. Pache, "Intelligent Cable Jetting (Blowing) Machine: Records Installation Parameters and Safeguards Cable", *Proc. 66th IWCS* (2017) 44-48.

[4] V.L. Streeter, "*Fluid mechanics*", McGraw-Hill Book Company, inc. New York, 3rd edition 1962.

[5] W. Griffioen, W. Greven, "Protected Microducts, Overview and Current Trends", *Proc 57th IWCS* (2008) 152-159.

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

[7] IEC 60794-1-21 (2015) *Optical Cable Test Procedures*.

[8] IEC 60794-3-11 Ed. 1 (2005) Part 3-11 *Outdoor cables - Duct and directly buried optical telecommunication cables - Product specification*.

9. Author

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. 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.