“Sonic Head”, a Pig Enhancing Several Techniques to Install Cables into Ducts in Many Ways

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Abstract

Today installing optical cables in ducts using compressed air (blowing) is common technology. Water instead of air is also used, and for energy cables this is the only alternative to pulling. In sloped trajectories water causes hydrostatic pressure, sometimes exceeding the maximum for the duct, especially when a pig is used (and this is often needed to keep the duct filled with water). The problem is solved by making the pig clever. This is done with a trick similar to the “sonic-head”, an accessory used already a long time with cable blowing. From time to time new benefits are discovered for this tool, a total of 10 now. They are summarized and discussed in this paper.

Keywords: Optical cable; energy cable; duct; blowing; blowing out; air; water; floating; pressure; slope; pig; sonic head; flexible; stiff; bend; coiled; tortuous; uphill; flow rate; water hammer.

1. Introduction

Blowing optical cables using compressed air is a worldwide used method to install them into ducts. Using water under pressure (floating) instead of air is another method, increasingly popular today. The latter technique is also used for the installation of energy cables. In case of sloped trajectories, first up than down, or with increasing downslope, parts of the duct might not be entirely filled with water, disabling drag force and buoyancy, hence reducing installation performance. In larger ducts pigs are used at the head of the cable, and the latter problem is not there anymore. But, here too much hydrostatic pressure might be built up, possibly resulting in bursting of the duct.

The solution to the problem was found using an old (1990) trick used with blowing cables, called the “sonic head” (name historically from sonic air velocity). This is a pig mounted at the front end of the cable which opens at a certain pressure. But now used with water. It has been analyzed which pressure setting is needed in sloped duct trajectories, and also how much water needs to flow through the “sonic head” in open condition, resulting in an optimum design.

It has been found that the “sonic head” can improve many cable installation applications and with surprisingly many functions (10 of them counted!). These benefits are discussed next, including the most recent features.

2. The Benefits

2.1 Blowing beyond “Critical Point”

The pressure profile in the duct is not linear, because air is a compressible fluid, resulting in increasing air drag forces on the cable towards the exhaust end of the duct (blue line in Fig. 1) [1,2,3]. When only gravitation friction counts (and that is approximately the case with cable blowing, where the cable axial tensile forces are kept low, avoiding the capstan effect [1,2,3]) the friction remains constant along the cable (red line in Fig. 1). In the example of Fig. 1 the duct length is chosen such that in the first part there is a deficiency and in the last part an excess of air drag forces. Nevertheless, the cable can be installed because in the first part there is assistance of pushing, reaching far because it does not have to do it alone. This synergy of blowing and pushing is often called jetting. The pushing force at the cable entry is calculated backwards from the foremost end of the cable, given for 3 starting positions in Fig. 1 (grey lines). As long as the red line is above the blue line, the pushing force at the cable entry grows when the cable foremost end is further away, until it reaches the point where the lines cross. Beyond this point there is a start with excess air drag forces, so the pushing force goes down first. It is clear that the maximum pushing force at the cable entry occurs when the foremost end of the cable reaches the point where the blue line crosses the red line, the so-called “critical point” [1,2]. This can be recognized by the pushing force at the duct entry as a function of installed cable length, the envelope of the calculated left points of the grey lines, represented by the green line in Fig. 1.

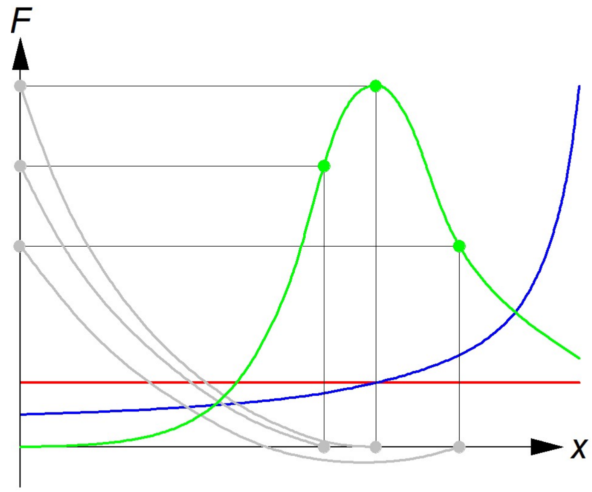

Figure 1. Forces *F* along duct as a function of position *x*: friction (red), air drag forces (blue), pushing force build up from different cable head starting points (grey) and envelope force at the pusher (green)

When a small force is applied to the foremost end of the cable, the grey lines and the green line in Figure 1 change drastically. The large effect of this small force is understood by the fact that in the low force area the force build up is not very fast, because of the even smaller capstan contribution here. The grey line starting from the critical point now ends at a much lower pushing value at the duct entry, see Figure 2. This is also true for the orange envelope line (which now not necessarily has its maximum in a critical point).

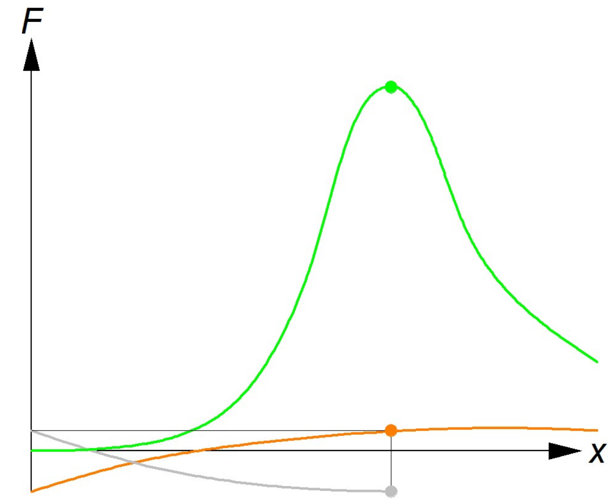

Figure 2. Forces as in Figure 1, but now grey line starting in "old critical point" with small pulling force (negative) from "sonic head". The envelope is now indicated orange and compared with the green envelop of Figure 1

The small force at the foremost end of the cable is applied by the "sonic-head", a pig with a leak such that a small pressure difference is present (to apply the small force) while the main airflow still goes through. The first design of a "sonic head" was made with a small hole, where air was flowing through at sonic conditions, acceleration of the air creating the required pressure difference. That explains the name. Today a design is used where the required pressure is regulated by a spring loaded valve, working for all fluids, air and water, see Figure 3

Figure 3. Example of a "sonic head"

In the early days the "sonic head" could give increase of blowing length by about 25%. That was in the time that the cable diameter was a factor of 2 or so smaller than the duct internal diameter. As the demand for fiber count was growing and continues to grow still, while the duct space is limited, the filling of the duct has grown considerably, with cable diameters even reaching 85% of the duct (internal) diameter. Improvement of cable design, optimized for blowing, has made this possible. As the hydrodynamic resistance of the part of the duct filled with cable is larger than that of the empty part, air drag forces are concentrated at the part with cable, see Figure 4. In Figure 4 the air drag forces at the "old critical point" have become considerably larger than the friction force, resulting in a much lower pushing force at the duct entry (orange dot) than for the situation without strong filling effect (old green dot). This continues when the cable advances. The "critical point" either shifts up or vanishes completely for high cable filling rates.

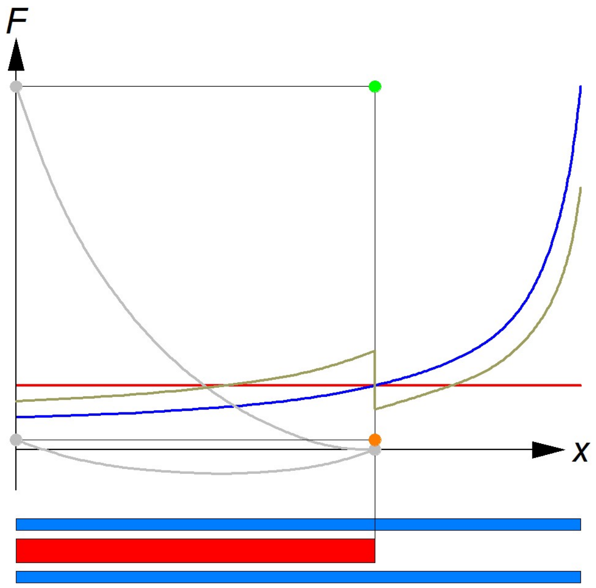

Figure 4. Forces when part of the duct is filled with cable. The air drag forces are now given by the khaki instead of the blue line. The grey lines are given for both situations, the orange dot for the filled situation

The "sonic head" (design with hole only still) was first used in the early "Sloten" FttH project in The Netherlands [1,4]. Here 4 mm optical drop cables were blown into 16/12 mm ducts to the houses. Although the majority of the cables is not suffering from the "critical point" barrier anymore, there are still advantages of the "sonic head' when the cable is flexible. The "sonic head" limits the tendency of the cable to buckle. This is true in general, and more particular when the cable is relatively small. This is treated in the next section.

2.2 Flexible and Relatively Small Cables

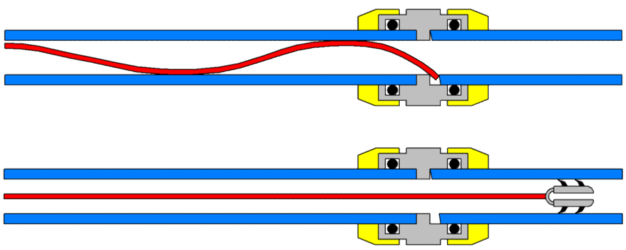

Figure 5. Small and flexible cable getting stuck in a duct coupling (top). When a "sonic head" is used this is avoided (bottom)

When cables are relatively small and flexible, the "sonic head" also helps in another way, both for installation with air and with water. Such cables easily get stuck in small gaps in duct couplings, see Figure 5. This is avoided when using a "sonic head", helping to pass small gaps in duct couplings, keeping the cable tensioned avoiding cable buckling, while the flow needed for the drag forces to advance the cable can still pass.

2.3 Blowing Out

When installing a cable into a duct with the help of compressed air, it benefits from the synergy between blowing and pushing, as mentioned in Section 2.1. This can lead to doubling of the distance that would be reached with pure blowing [1,2]. When cables need to be blown out, e.g. for replacement, there is no pushing force anymore. This leads to considerably shorter blowing out than blowing in lengths. This fact is known by many installers. When blowing tests are done, the pressure is then limited to e.g. 70% of the maximum pressure, allowing to blow the cables out. When this is not the case, the duct is opened at a shorter length for this. The same is true when installed trajectories need replacement. When the installation lengths and pressures were recorded, e.g. by means of intelligent jetting equipment [5], the locations where the duct need to be opened can then be estimated.

In the case of blowing out a cable the "sonic head" can be used as a pusher, applying a pushing force that might be small, but sorting a substantial effect on the blowing out length. In Figure 6 the green line represents the old blowing in pushing force envelop, with "critical point". The friction and air drag forces, red and blue line, respectively, are drawn for a shorter blowing out length. The blue line starts with a slightly higher force compared to the blue line for blowing in (the red line remaining at the same force) and crosses the red line also earlier, absolutely, but also relatively (compared to the new red line). This results in a new (orange) pushing force envelop, with the critical point at shorter distance and lower force (the force of the "sonic head") than for blowing in. But not such a short distance as when no pushing force was applied at all, when the blue line needs to "tangent" immediately the red line at the duct entry.

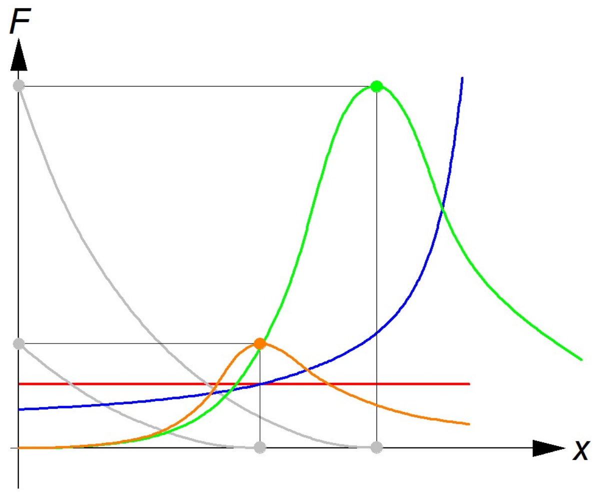

Figure 6. Blowing out with "sonic head". Duct shortened a bit compared to blowing in length. New "critical point" (orange) at shorter distance and lower force than critical point for blowing in (green)

Depending on the stiffness of the cable and the tortuosity of the duct trajectory, the blowing out length when using a "sonic head" is typically in the range of 80-95% of the blowing in length, while this would be in the range of 50-80% when no "sonic head" was used with blowing out. These figures are theoretical, and not much experience was gained, simply because the "sonic head" is made for pulling on the front end of the cable. In order to push, and open at the right pressure, improvisation is needed to mount it at the rear end of the cable, or a pushing accessory is made (available soon). However, the first experience with a micro "sonic head" confirmed theory. In a 1200 m long 3-phase power cable 10/8 mm microducts were stranded with the construction. This cable was laid out along a road, see Figure 7. In one of the microducts a 5.4 m optical cable was blown in. Blowing out was not possible anymore, also not when a higher pressure was used. When a micro "sonic head" was used blowing out was successful.

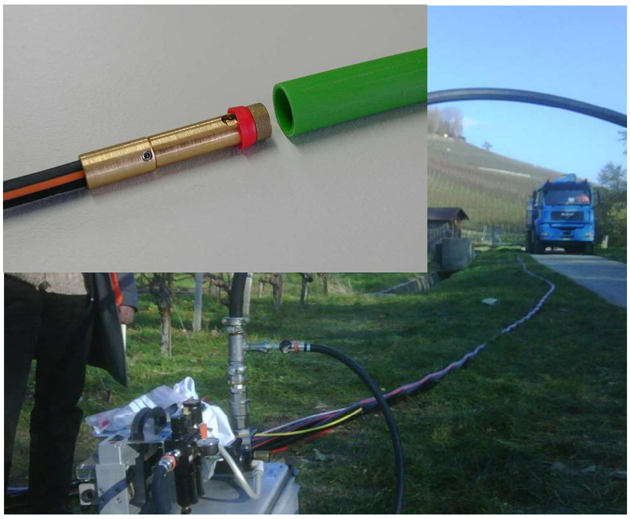

Figure 7. Blowing out with "sonic head". First prove.

2.4 Stiff and Relatively Large Cables in Coiled Duct

Figure 8. "Sonic head" used to install 646 m of 82 mm power cable into 125/102 mm duct coiled with 2 m radius

Another use of the "sonic head" is to enhance (make possible) installation of relatively stiff and large cables into coiled trajectories, with air or water [6]. To bend the front end of the cable into the coiled duct, a friction and counter force need to be overcome [1,2,3]. Such a local force might kill the trick of keeping the forces in the cable low by exerting a distributed drag force to compensate for the (gravity) friction. This is especially the case in coiled (or extremely tortuous) duct trajectories, where the action of excess fluid drag forces (by selecting a shorter duct length) is short, so lacking building up sufficient forces to push the cable front end through the bend. Two examples of such installations are given. The first one is a large size extreme. With a mega "sonic head" the "impossible" job of a 3 phase power cable of 82 mm diameter into a 646 m long 125/102 mm duct, coiled with a bend radius of 2 m, was installed successfully with water, see Figure 8 (presented at [7]). The second small size extreme is installing a bare optical fiber or a small optical cable, again with water, into a coiled steel tube, with typical inside diameter of 2-4.5 mm [8], see Figure 9. Here relatively stiff and large are with respect to the small tube size and also the small coiling radius (in the order of 0.35 m). It was found that with a bare end the fiber or cable it will get stuck in the "outside" laminar zone of the coil. And with flushing out also a rear pushing force is needed, to avoid getting stuck in the "inside" laminar zone (even when a "sonic head" is used at the front end).

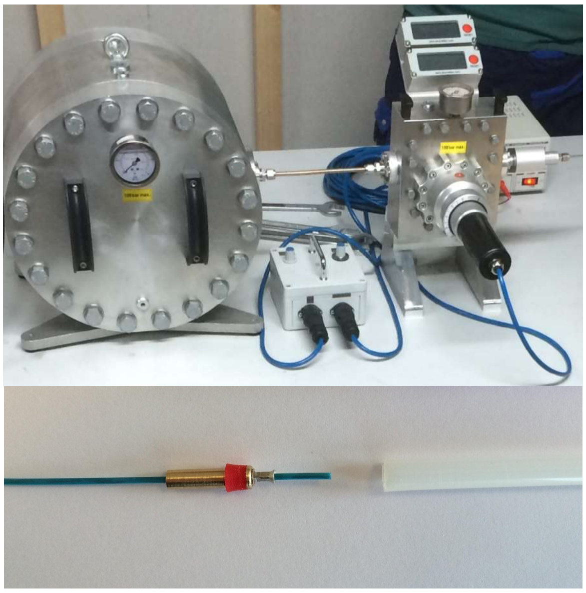

Figure 9. "Sonic head" used to install bare fibers or small cables in steel tubes with typical 2-4.5 mm internal diameter coiled with 0.35 m radius

2.5 Stiff and Large Cables, Relatively Sharp Bends

To install relatively stiff and large cables into duct trajectories with some tortuosity and relatively sharp (compared to rest of trajectory) bends (isolated) with air or water. The cable experiences friction and counter forces in these bends, like in Section 2.4, inducing the last obstacle for reaching long lengths. This is also true when the cables are not large and stiff, especially when water is used to generate fluid drag enabling record lengths (> 10 km).

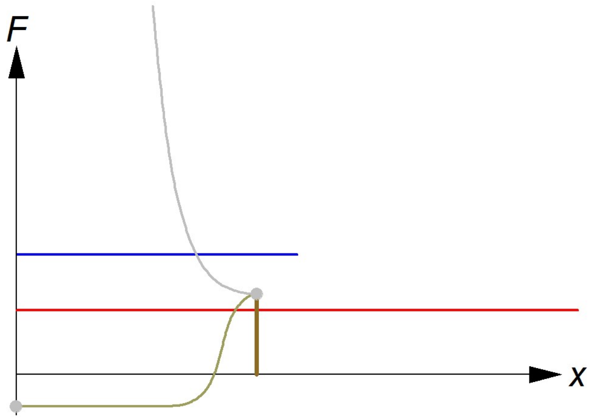

Figure 10. Friction force (red line) drawn over maximum duct length, where water drag force would exactly match. Force build up from local force (brown) for this case to pass bend shown grey. Changes to khaki line when duct shortened to length of blue line, with higher drag force

An explanation is done for installation with water, where the effect is most clear. In Figure 10 the situation is shown for installation with water in a duct with some tortuosity (almost always the case) and an isolated relatively sharp bend. The red line indicates gravity friction force over the maximum installation length, where water drag forces exactly match gravity friction (so the blue line is not visible for this case). This length can only be reached when the axial force in the cable remains zero (no capstan effect). This is not the case anymore when a local force to pass an isolated bend is present, given by the brown bar. The force build up explodes now, because of the capstan effect in the duct trajectory (with some tortuosity). In order to install the cable the duct length must be shortened, indicated by the blue line, also representing the resulting larger water drag force, until the excess fluid drag forces exceed the local capstan forces and the force build up bends down (khaki line). This bending down depends on duct tortuosity. The excess water drag forces transform the pushing force to a pulling force, stabilizing at a level again depending on duct tortuosity.

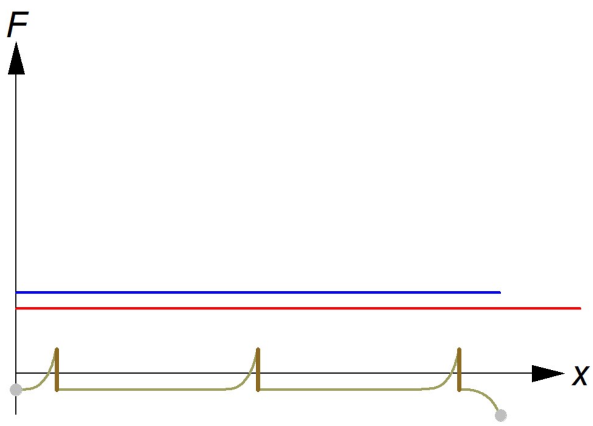

Figure 11. Same as Figure 10, but now with "sonic head" used (and multiple bends) and duct only shortened a bit

In Figure 11 the situation is shown when a "sonic head" is used. The duct length (indicated by the blue line, just above the red line) is longer than in Figure 10 and there are multiple bends. Starting with a small "sonic head" pulling force, the force build up stabilizes again (but at a little lower value than in Figure 10, because the excess water drag forces are less). When a bend is met a force step is made. But, besides starting with a small pulling force, this step is less than in Figure 10, because the cable passed the bend already, resulting in a lower friction force, and no counter force [1,2,3]. The force then bends down again, readily stabilizing. It can be seen that the bends hardly "see each other", when placed at sufficient intermediate distance. In very straight duct routes the "sonic head" can make installation lengths 100% larger, or even more!

Figure 12. Test trajectory in Bex with ducts in bends in orthogonal planes

In Bex tests were done, blowing a 1728f non-slotted core cable [9], diameter 23 mm, containing 2 strength members, into a trajectory with 40/35 mm duct of 200 m long and with many bends, including bends in orthogonal planes, see Figure 12. Because of the 2 strength members the cable shows 2-dimensional bending properties. Together with the different planes of the bends this leads to a high force for the cable to pass those bends. Blowing was done with a hydraulic Jetting machine and a small (3.15 m^3/min) compressor (only 3 bar air pressure could be reached in this duct). The hydraulic pressure (indication for pushing force) needed to blow the cable through was 50 bar, but when the cable head was in the bends with different planes the hydraulic pressure rose to 90 bar. When a sonic head was used this was only 65 bar. More spectacular results are expected when installation is done with water instead of air.

2.6 Steep Uphill Sections in Duct Trajectory

Figure 13. Example of long length installation with water with steep uphill section at the end

To install cables into trajectories with steep uphill section (at the end) with air or water. This situation is similar to the situation of Section 2.5, with the steep uphill section in the role of the bend (the weight of the cable counts more here than its stiffness). With air the last section is usually not a problem, when the uphill section is not too large, because of the excess air drag at the end. So, the benefits are most clear for installation with water (although there the force to pass the uphill section can be minimized by matching cable and water density). An example is installation with water of an export cable to a platform feeding an offshore wind park, see Figure 13, where the arrow indicates the obstacle. Note that for this situation also other solutions exist, like using a pilot line in front of the cable, or picking up the cable with a pulling rope with hook.

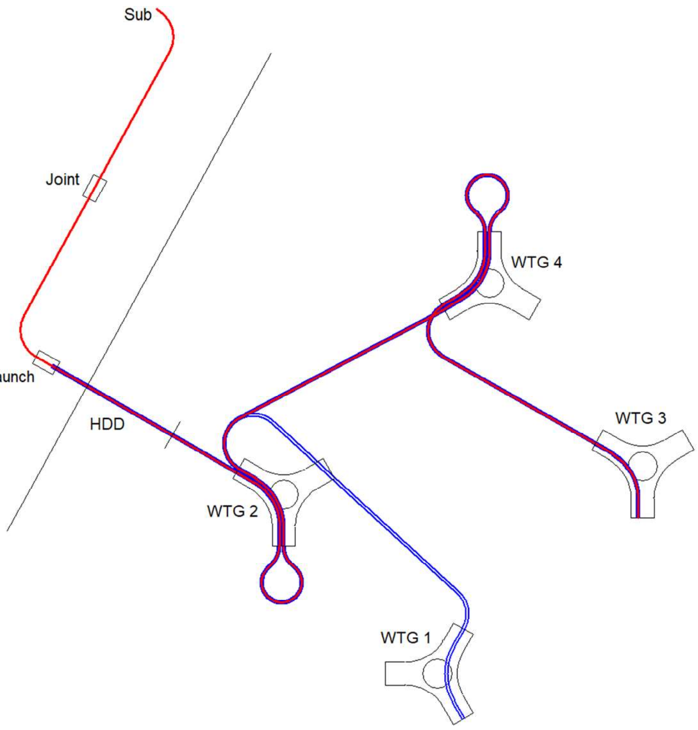

Figure 14. Offshore wind park where power cables and optical cables were installed in ducts

The beneficial effect of the "sonic head" for duct trajectories with steep uphill parts is not only limited to large power cables. Smaller optical cables benefit as well. In an offshore wind park with 4 wind turbines both the power cables and the optical cables were installed in ducts with assistance of water, see Figure 14. For installation of the 7.5 mm optical cable into the 40/33 mm duct a "sonic head" was used. Installation was done with a water pressure up to 17.5 bar over a total length of max 3.8 km. In the wind turbines not only vertical rises were present in the J-tubes (about 20 m, but also another 20 m at the end of a HDD drill), but also a lot of bends (including the looping back of the duct to the next turbine). Nothing could be seen during installation when the front end of the cable passed the vertical rises.

2.7 Sloped Duct, Keep Water, Avoid High Pressure

This feature is limited to installation of cables into ducts using water. When the duct trajectory is sloped, the hydrostatic pressure build up has to be taken into account: about 1 bar per 10 m elevation difference. Usually cable installation is done from the highest elevation, enabling longer cable lengths. But, when a pig is used at the front end of the cable, a too high water pressure might be built up, e.g. with risk of bursting the duct. On the other hand, when no pig is used there might be not enough pump capacity (flow rate) to keep the duct filled with water (and benefit from buoyancy, only relevant for the part of the duct filled with cable). And, when a downhill slope follows after a horizontal or even uphill section, the downhill part might even not be filled when sufficient pump capacity is available. A solution to this problem is using a "sonic head" at the front end of the cable. It can be set to the right pressure such that the maximum (duct) pressure is not exceeded at any part of the trajectory, while keeping the duct filled with water. An example is given in Figure 15.

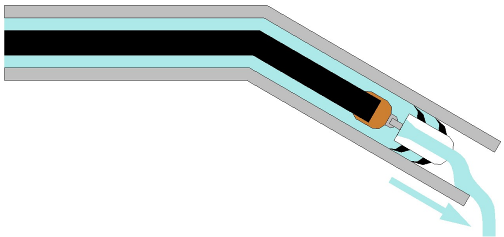

Figure 15. Example of "sonic head" keeping cable part of duct filled with water, limiting maximum duct pressure

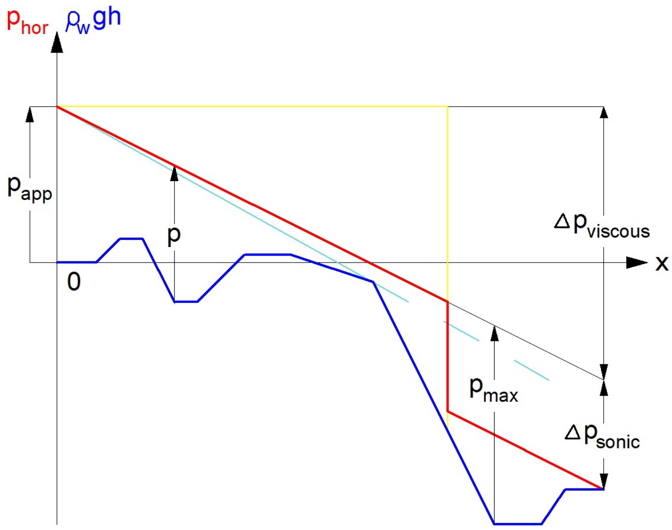

Figure 16. Diagram to determine setting of the "sonic head", for details see text.

In Figure 16 an example is given how to set the right pressure difference Δp_{sonic} over the "sonic head", depending also on the pressure p_{app} applied at the duct entry. Here the water pressure p_{hor} is drawn (red line) as a function of the position x in the duct as if it were horizontal, i.e. solely determined by the viscous pressure loss (described by Blasius' law [1]) and with a step Δp_{sonic} at the location of the "sonic head". Also drawn is the hydrostatic height function $\rho_w g h$ (blue line, the 1 bar hydrostatic pressure per 10 m elevation difference), with ρ_w the density of water, g the acceleration of gravity and h the elevation with respect to the duct entry. It follows that the effective local pressure p in the duct is the difference between the red line and the blue line. When the duct is entirely filled with water, the red and blue line meet each other at the end of the duct (where the local effective pressure is zero). At the position of the "sonic head" shown, the duct can remain totally filled with water. This is not the case anymore when the "sonic head" is positioned further to the left, touching the blue line and moving steep up. In this case the slope of the red line left of the "sonic head" is less steep, i.e. less water is flowing through the duct. For the red line to meet the blue line at the duct end, its slope needs to be steeper at right of the "sonic head" than at left. The duct between the "sonic head" and the end of the duct will not be filled with water. No problem, because there is no cable here that needs buoyancy.

When the "sonic head" moves to the right, the maximum effective pressure p_{max} is reached at the location indicated. It is possible to select other combinations of p_{app} and Δp_{sonic} such that the pressure is limited to the same maximum at any location. It is possible to go for a maximum flow (steepness of the red line) or for a maximum force on the cable front end (pressure difference over "sonic head") and a minimum flow. The latter mode might give longer installation lengths in duct trajectories with not too many bends. Also this mode is required when the pump capacity (flow) is limited. When many bends and/or undulations are passed and sufficient pump capacity is available the large flow mode could be a better solution.

When no "sonic head" is used cable installation would be more difficult. In Figure 16 the situation is shown with the magenta line where no pig is used at all. When the point where the magenta line touches the blue line is passed, the duct will not anymore be entirely filled with water. For that the magenta line needs to bend down steeper after this point, meaning a higher water flow which cannot be fed through the first duct section. So, the cable will "run dry" when passing this point, lacking buoyancy. The pressure p_{app} cannot be raised sufficiently (respecting p_{max} at all locations) to avoid this. The yellow line in Figure 16 shows the situation that a tight pig is used. It is clear that p_{max} is amply exceeded.

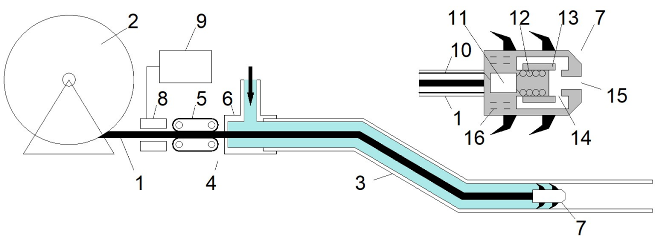

Figure 17. Example of intelligent "sonic head"

The "sonic head" can be set to the right pressure, such that with the applied pressure the maximum effective pressure in the duct is not exceeded at any position of the sonic head. It is also possible to adjust the applied pressure during the installation, getting the maximum performance and still respecting the maximum pressure at all times and at every location. It some cases it would help if the setting of the "sonic head" could be modified during installation.

This can be done when making it intelligent. For example, the "sonic head" could be pre-programmed to regulate its pressure difference as a function of its position, which can be measured locally, e.g. using track wheels. It is also possible to "communicate" between the "sonic head" and the duct entry, e.g. by means of inductive coupling to the cable shielding, see Figure 17.

2.8 High Flow Rate Backup Tortuous Duct

Installation of energy cables into ducts with assistance of water can be done without a pig at the front end of the cable (called Floating) or with a pig (called WaterPushPulling) [10]. The latter technique is used when the ducts are large (internal diameter typically larger than 100 mm), to limit the size of the pump (capacity, flow rate). Because the pulling force is concentrated at the front end of the cable, this method suffers from the capstan effect. Often duct trajectories for power cables do not contain a lot of bends, so good results are reached, up to 3.3 km in one "pull". But, when it appears during installation of the cable that unexpected tortuosity is found in the ducts, e.g. by twisting of a bundle of ducts pulled into a HDD drill, like in Figure 18, the cable might not reach the end. And pulling back the cable is also a problem, especially when the lip seals of the pig get stuck behind (mirror) welds in the duct. The solution is again building a "sonic head" function into the pig. Let it pull until a certain max pressure. But, when the cable gets stuck it is time to getting a larger pump as a backup solution (everything better than the cable being stuck forever). This pump can then operate above the max set pressure of the pig, which then opens for Floating. Now a distributed drag force is exerted too on the cable, limiting the capstan effect and saving the job.

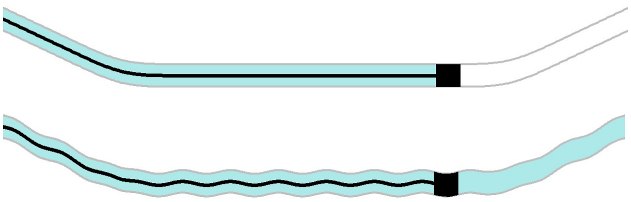

Figure 18. Cable WaterPushPulled (top) in the duct. When unexpected duct tortuosity is found (bottom) a "sonic head" function can be used to save with Floating

The above backup solution is illustrated by the following example. A 102 mm cable is installed into a 200/163 mm duct in a HDD drill of 1350 m long by WaterPushPulling (with pig). There are not many bends in the trajectory and installation can be done with 2.75 bar water pressure. A water flow of 190 l/min is sufficient to install with a speed of 15 m/min (less flow only would reduce the speed). For Floating a pressure of 7 bar and a flow of 1800 l/min would be required, much more than the 300 l/min pump used can supply. But, the unexpected twisting of the duct, with a pitch of 9 m, stops the cable. Not strange, because for any pitch smaller than 22 m the cable could not be installed by WaterPushPulling. But, when a "sonic head" function was built in the pig, opening at a pressure of 6 bar, the situation could be saved when larger pumps are brought to the site. The surplus pressure is then used as Floating, with distributed drag forces on the cable taking care of the capstan effect in the twisted duct. A flow of 2000 l/min (requires sufficient size of the opening in the pig) and a pressure of 15 bar (total) would do the job.

2.9 FreeFloating Alternative Setting

Once the cable is entirely installed in the duct by WaterPushPulling, it can be "tube posted" to further duct sections by FreeFloating [10]. For this a second pig is pushing the rear of the cable. In order to share the pressure, the pigs are equipped with a small opening of equal size, such that a small (equal) flow of water goes through both pigs causing the same pressure difference over both pigs. It is also possible to set the pressure difference over the pigs with "sonic head" valves. They can be set a bit asymmetric, e.g. a bit more pulling than pushing. It is also possible to use a part of the pressure difference for a water flow with higher speed than the cable, such that also a distributed drag is exerted on the cable (Floating). This might help when the duct trajectory is tortuous. However, the combination of FreeFloating and Floating cannot be done over too long duct lengths, because the trick of FreeFloating that viscous losses of the flow can be set to a minimum by selecting a low cable speed does not work then anymore (for Floating to be effective the water itself needs to have sufficient speed). FreeFloating is used for power cables, but can in principle also be used for optical cables when the right boundary conditions apply.

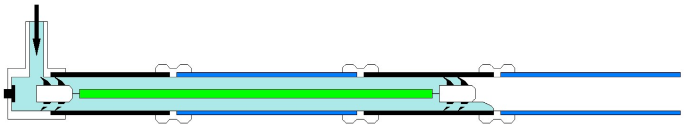

Figure 19. FreeFloating the cable to further duct sections

2.10 Limit Pressure of Water Hammer

When the cable and pig suddenly stop inertia of the water column behind the pig creates a pressure surge, called water hammer. This might cause damage to pig and duct. The magnitude of the water hammer depends on the speed of the water column and cable. The "sonic head" can also serve as a safety valve, to protect pig and duct. The opening in the pig shall be large enough to accommodate the flow. The amount of water released not only depends on the speed, but also depends on duct size. When for example the cable is FreeFloated with a speed of 30 m/min inside a 163 mm ID duct a release of 626 l/min is required. Plus a bit extra for the standard opening in the FreeFloating pigs. This is less than e.g. the "backup flow" in Section 2.8 for the same duct size (and also less than the required flow in most cases of Section 2.7).

3. Conclusions

A new application for a pig opening at a certain pressure ("sonic head") at the front end of the cable to enhance installation with assistance of a fluid under pressure has been found. In this case the fluid is a liquid, e.g. water. The "sonic head" takes care that the part of the duct where the cable is present remains filled with water, while limiting the pressure to a max value. Although developed for installation of power cables, it can also be used for installation of optical cables. The new application adds to the functions found earlier, which led to already 3 patents: 1) blowing beyond the critical point, 2) installing flexible and small cables avoiding getting stuck and buckling, 3) blowing out, 4) installing in coiled ducts, 5) installing in trajectories with sharp bends, 6) installing in trajectories with steep uphill sections, 7) keeping water in duct while limiting pressure, 8) high-flowrate backup, 9) alternative FreeFloating setting and 10) protecting against water hammer.

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5. References

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

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

[3] W. Griffioen, H.G. Nobach, G. Plumettaz, "Theory, software, testing and practice of cable in duct installation", *Proc 55th IWCS* (2006)

[4] Tromp, H.R.C., Nijnuis, H.T., Boomsma, Y., Bakker, J., "Fiber to the home in the Netherlands", *Proc. 9th Int. Symp. on Subscriber Loops and Services* (1991) 253-259

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

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

[7] W. Griffioen, "New techniques to install high voltage cables into ducts", *ICC Fall meeting*, 30 October – 2 November (2016). Presentations in Transnational lunch and in Subcommittee C.

[8] W. Griffioen, Y. Chappuis, S. Grobety, "Progress in Floating Sensor Fibers into Steel Tubes", *Proc. 65th IWCS* (2016) 59-66

[9] F. Sato, K. Tsuchiya, Y. Suzuki, M. Takami, T. Hirama, W. Griffioen, "Designs of New UHFC Optical Fiber Cables with Freeform Ribbons and Installation Characteristics", *Proc. 67th IWCS* (2018) Session No. 10-3.

[10] W. Griffioen, C. Gutberlet, J. Mulder, L. Højsgaard, W. Grathwohl, H. Bringsell, J. Sørensen, N-J. Borch Jensen, "New approach to installation of offshore wind energy cables", *Proc. Jicable*, Versailles, 21-25 June (2015) paper B4.1.

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