NEW TECHNIQUE TO INSTALL POWER CABLES INTO DUCTS

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ABSTRACT

An improved method to install high voltage cables into ducts using water flow is described. Instead of using a single pig, a number of (dividable) Multi-Pigs are mounted around the cable, exerting a distributed force resulting from the equally shared pressure differences over each pig. Because the capstan effect is reduced the installation lengths are increased considerably, while pulling forces on the cable remain small. The Multi-Pigs can also be used to flow cable lengths to any desired location, loose from the cable insertion equipment. This is especially of use in difficult to reach (for cable drums) places, e.g. tunnels.

KEYWORDS

Cable installation; duct; jetting, floating, pushing, water, pressure, pig, multi-pig, free flowing.

INTRODUCTION

There is a growing trend to get high voltage energy cables underground [1]. Compared to direct burying the cables, the adoption of ducts offers the benefit of drastically reduced disturbance to the neighbourhood, provides for additional cable protection and enables upgrading of the cable connection [1]. Furthermore, the duct can optionally be used for cooling, with gas (air) or liquid (water), passive or active, to allow for higher current loads [2].

The classical method to install high voltage energy cables into ducts is pulling by means of a winch rope. This technique is costly, limited to relatively short lengths, requires the extra step of installing a winch rope, requires manpower at both ends (drum side and winch side) and also causes wear of the cable because of the high pulling loads. An improvement of the pure pulling method is the push pull method, where the pulling is assisted by a cable push at the drum side. For aluminium high voltage energy cables, which are relatively lightweight, the WaTuCab (Water Tube Cable) method offers a further advantage [1]. Here, installation is done by means of a pulling pig (no more pulling with winch rope from other side) that is "powered" by means of water under pressure, also offering reduction in the effective weight of the cable because of buoyancy (Archimedes effect).

In this paper an improved method for the installation of cables using water is described. Instead of using a single pig, a number of (dividable) Multi-Pigs are mounted around the cable, exerting a distributed force resulting from the equally shared pressure differences over each pig. Because the capstan effect [3] is reduced the installation lengths are increased considerably, while pulling forces on the cable remain small. The Multi-Pigs can also be used to flow cable lengths to any desired location, loose from the cable insertion equipment. This is especially of use in difficult to reach (for cable drums) places, such as tunnels.

THEORY

The force to install a cable into a duct is caused by sidewall forces between cable and duct, resulting in friction. The following effects contribute to the pulling force build-up in the cable [3,4,5]:

1. Cable weight (gravity). This results in a pulling force that is proportional to the installed length of the cable.
2. Cable tensile force. In bends and undulations of the duct this causes a sidewall force proportional to the local tensile force in the cable. This results in a pulling force that increases exponentially with the installed length of cable. This effect is known as the Capstan effect. It dominates most cable pulls.
3. Cable compressive force. The same Capstan effect is present for compressive forces. Additionally also the cable buckles under the compressive forces, causing additional sidewall forces. This leads to an asymptotic pulling force built-up: from a critical force the cable cannot be pushed any further. The smaller the cable stiffness, the larger the buckling friction.
4. Cable stiffness in bends and undulations in the duct trajectory. This results in extra friction. For the cable head in a bend the effect is even larger. The higher the cable stiffness, the larger the friction from cable stiffness in bends and undulations in the duct.

Jetting

Some methods have been found to limit the force build-up. More than 2 decades ago, in telecommunications, the jetting method has been introduced [3,4,5]. An airflow is forced into a duct, while at the same time pushing the cable. There is no pig at the end of the cable, so the air can flow at much higher speed than that of the cable. This storm generates a cable propelling force that is distributed over the entire length of the cable. When dimensioning such that the air propelling force locally compensates the friction caused by the cable weight (effect 1), the local force in the cable can be kept low. This eliminates effects 2 and 3 for a large part. Even though the air drag forces are an order of magnitude smaller than commonly used forces to pull a cable, installation lengths by jetting usually exceed those obtained by pulling, especially in duct trajectories with many bends and undulations. Also no winch rope needs to be installed and manpower is only needed at one side. Today the jetting method is widely used all over the world to install telecommunications cables into ducts. Installation lengths of up to 3.6 km (in one "jet") have been reported.

Floating

Instead of air also water can be used [1,3,4,5,6]. This causes a reduction of the effective weight of the cable because of buoyancy (Archimedes effect). It would even be possible to tune the cable density such that the effective cable weight becomes zero.

Now effect 1 is also reduced or even eliminated. The only remaining effect then is effect 4. This method is called floating and record lengths of up to 10 km have been obtained. Needless to tell that now the installation is ruled by effect 4, the last friction contributor. So, bends in ducts shall be not too sharp, and undulations in duct and even cable shall be limited (especially when there is little free space for the cable in the duct).

Water Tube Cable Pulling

Jetting is limited for ducts with ID of up to 45 mm, while for floating this limit is about 50 mm. For larger duct sizes larger compressor or pump capacities are required than commonly available for use in the field. To decrease the flow it is needed to attach a pulling pig at the end of the cable. Now the pressurized air (better avoid this at very large ducts, because of safety) or water is just moving with the same speed as the cable and the entire force is exerted at the pig at the cable head. Unfortunately, the Capstan effect is back again. Nevertheless, still long lengths (in the order of 3 km) have been reached with this method when using water, while still assisting with cable pushing. This installation method uses water as a carrying fluid do install power cables in ducts [1,6,7,8,9]. Forces exerted on the cable are much smaller than for traditional pulling, reducing wear. There is no need to first install a winch rope. Also there is no need to place equipment at the far end of the duct. The method is especially suitable for cables with aluminum conductors, but also cables with copper conductors can be installed economically.

MULTI-PIG

With the improved method of Multi-Pig [10] the advantages of floating and WaTuCab are combined. Also here pulling pigs are used, but now more than one. The force over a single pig is shared by a number of pigs, placed at regular intervals along the length of the cable, see Fig. 1. The intervals are chosen such that just when the capstan effect starts to dominate a new pig is placed. In this way much longer installation lengths are reached, while the forces on the cable. i.e. cable wear, are further reduced. In routes with many bends, doubling of the installation length of single pig techniques (e.g. 6 km in one go) is possible.

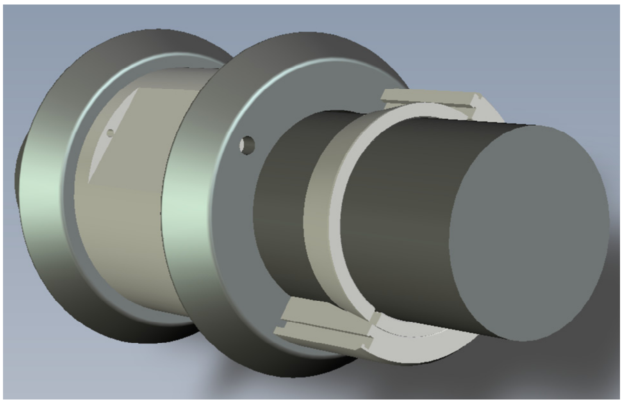

Fig. 2: Multi-Pig

The pigs are equipped with differential pressure regulating functionalities. In its simplest form, see Fig. 2, these are just orifices of dimensions such that at given water flow (which has to flow a little faster than the cable) the required pressure is obtained. This differential pressure will be the same for all pulling pigs when they are equipped with equal orifices. Differential pressures over the pulling pigs can then be controlled by controlling the inlet pressure, i.e. the sum of all differential pressures. The pig is dividable and can be mounted around the cable. Conical teethed rings grip the cable when the pig is pushed forward, see Fig. 2 and Fig. 6.

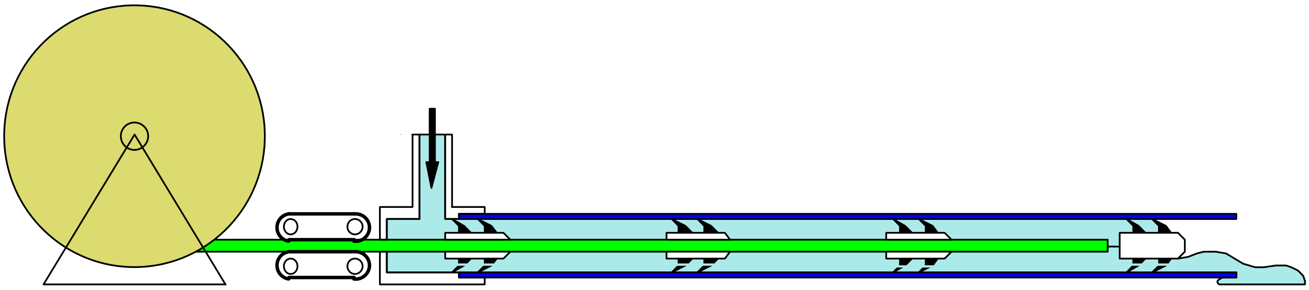

Fig. 1: Cable installation using water flow with multiple pulling pigs placed along the cable

Example

The following examples illustrate the beneficial working of using multiple pulling pigs, each taking a part of the available pressure, instead of one pulling pig at the front end of the cable taking the full pressure. In the example a cable with a diameter of 66 mm, weight 43 N/m and stiffness 1300 Nm^2 is installed in a duct with inner diameter of 102 mm that shows undulations with amplitude of 15 cm and period of 15 m (these parameters include effectively the few bends that might also be present along the trajectory). The cable is installed using water under a pressure of 12 bar, exerting a pulling force on one or multiple pulling pigs. The buoyancy of the cable in the water causes the weight of the cable to drop to 9.44 N/m effectively. The coefficient of friction between the cable and the duct in this situation is taken as 0.14. At the entry side the cable is pushed into the duct with water under pressure with a force of 14000 N. Inside the duct this gross pushing force has dropped to net 9895 N, after overcoming the pressure drop over the cable inlet. The build-up of the pushing force is calculated with a computer program that is based on formulas from [3,4,5].

1 pulling pig, 12 bar

With 12 bar over the pulling pig a force of 9805 N is exerted on the front end of the cable. In Fig. 3 the pushing force is shown as a function of the location of the front end of the cable. After a length of 3000 m the maximum net pushing force of 9895 N is reached.

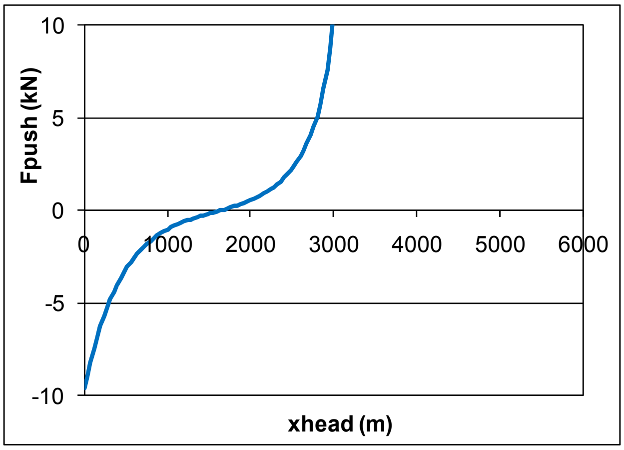

Fig. 3: Pushing force as a function of position of cable head for 1 pulling pig at cable head

2 pulling pigs, each 6 bar

With 6 bar over each pulling pig, a force of 4903 N is exerted over each pulling pig, at the front end, and after 2200 m, where the second pig is mounted. In Fig. 4 the pushing force is shown as a function of the location of the front end of the cable. After a length of 4600 m the maximum net pushing force of 9895 N is reached.

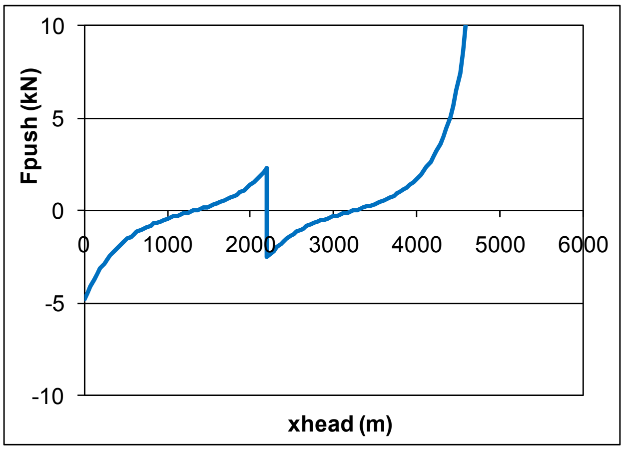

Fig. 4: Pushing force as a function of position of cable head for 2 Multi-Pigs, intermediate distance 1500 m

3 pulling pigs, each 4 bar

With 4 bar over each pulling pig, a force of 3268 N is exerted over each pulling pig, at the front end, after 1725 m and after 3450 m. In Fig. 5 the pushing force is shown as a function of the location of the front end of the cable. After a length of 5650 m the maximum net pushing force of 9895 N is reached.

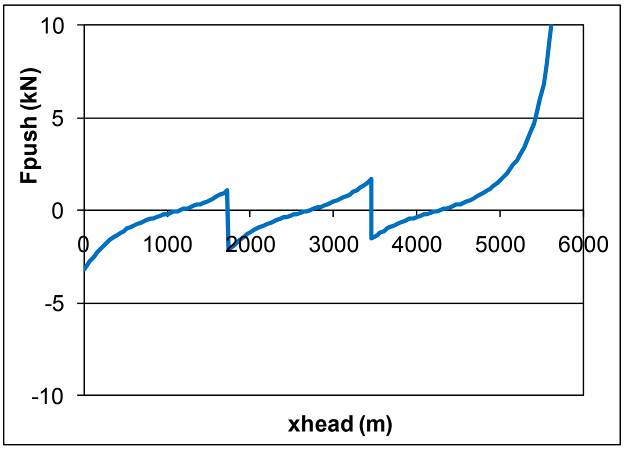

Fig. 5: Pushing force as a function of position of cable head for 3 Multi-Pigs, intermediate distances 1200 m

It becomes clear that distributing the pressure over multiple pigs increases the installation length, in this example by a factor of almost 2. For trajectories with more bends and undulations the benefit becomes even more, for more straight trajectories the benefit becomes less.

Use in the field

The pulling pigs remain in place after installation, so are made entirely non-metallic. It is possible to flow out the water through the orifices (when needed evaporate / flow out the last bit when the cables are heated up during electric testing). The pulling pigs are dividable and can be placed in several ways. One way is to stop the installation and open the equipment for placing new pigs (installation can be restarted easily after a stop).

An example of an automatic loading station, which does not need opening during launching of new pigs, is shown in Fig. 6. To launch a new pig, sleeve 104 is pushed back (e.g. magnetically) so water is forced to flow through the pig. At the same time lock 102 releases holding fork 76 (will be pushed outwards by the water pressure) and the pig will be pushed forward by the water pressure difference, while the conical teethed ring 78 grips onto the cable jacket when it leaves the hard tube 74.

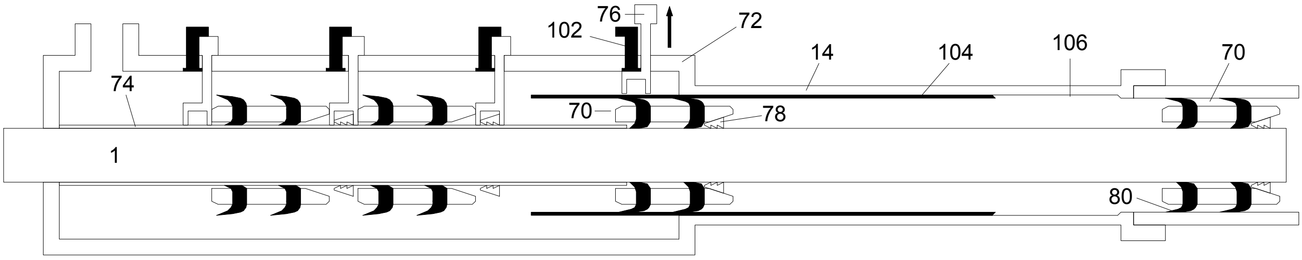

Fig. 6: Example of launching chamber for Multi-Pigs

FLOWING CABLE TO DESIRED LOCATION

The Multi-Pigs can also be used to propel a cable in a duct when the cable is already loose from its installation equipment. For this the full cable length must be present inside the pressurized duct. This is especially useful when a cable length must be transported to a duct section where there is no access for cable installation equipment or cable drum, e.g. in a tunnel. Today´s trend that cable installation lengths increase, to save on expensive splices, makes that drums are getting bigger indeed.

In order to propel a cable in a duct that is much longer than its own length, preferably at least 2 of those Multi-Pigs are beneficial [11]. The pigs take care that the main pressure drop is over the cable, and almost negligible in the duct sections where no cable is present. In straight sections, like said tunnels, a pig at the front and at the end of the cable suffices, so traditional pigs can be used, without the need to clamp around the cable, and easy to remove after installation of the cable. However, the pressure sharing mechanism must still be present. An example with 2 pigs and 2 cables is shown in Fig. 7.

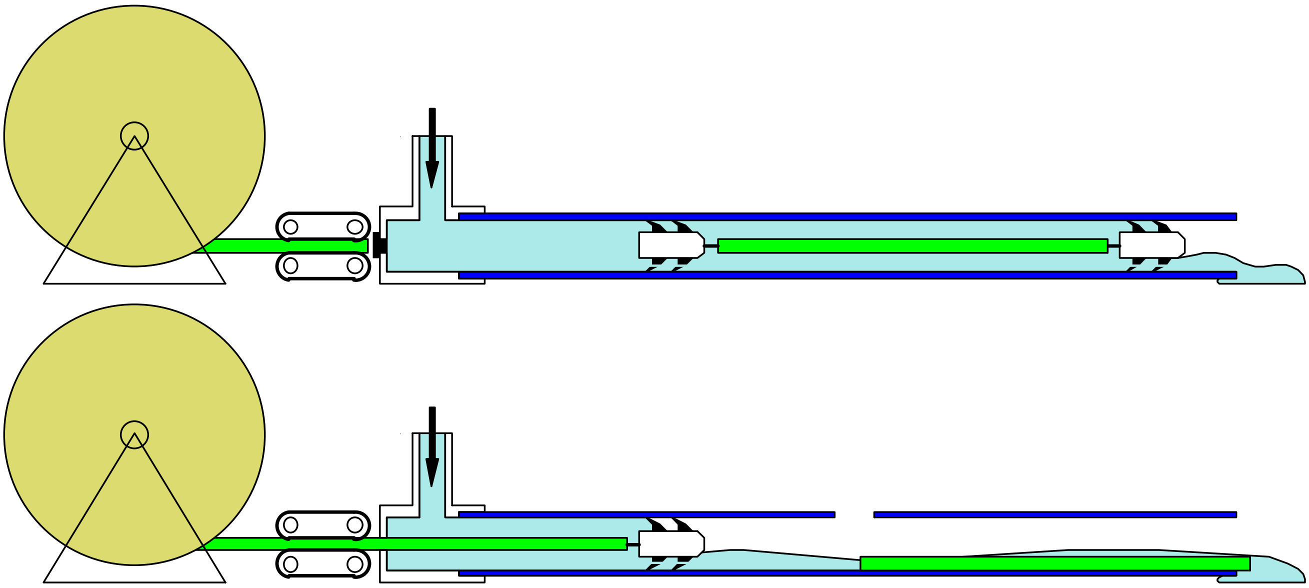

Fig. 7: Example of flowing cable to desired location with pig at cable front- and back-end (top). When first cable is installed, these pigs are removed, the duct opened immediately after cable, and second cable installed (bottom).

The procedure is as follows. The first cable is installed in the “traditional” WaTuCab way, with a pig at the cable´s foremost end. Difference with the WaTuCab system is that now the pig is equipped with pressure regulating means, e.g. an orifice of the right size. When the drum is empty and the cable is in the duct a second pig is mounted at the cable´s back end. This pig is equipped with the same pressure regulating means. Next the duct at the cable´s back end is closed. For this it might be required that a temporary piece of duct is coupled to get enough length for closing around the cable and the pig (not shown in Fig. 7). After closing the duct, the water is put under pressure again. At the right settings the cable starts moving again. Now the cable goes with the flow (this is the situation in the top of Fig. 7). In this situation the water flows with a certain speed through the pigs (is speed with respect to the cable) to build up enough pressure to obtain the pushing force to overcome the friction of the cable in the duct. The net speed of the water (water speed in duct subtracted with speed through pigs) is equal to the actual cable speed. The speed can be controlled by setting the right input pressure. The pigs can be equipped with transmitters, so that the cable can be followed during installation. When needed, especially in case of steep downhill slopes, the cable can be slowed down by means of an exhaust valve for the water at the duct end. For this the duct has to be filled with water over its entire length first.

Note that in order to obtain the same length with “free flowing” as with WaTuCab, some extra water pressure is required for powering the rear pig, in its role as the pusher. For this the duct will have to be pressurized a little more, but the pressure drop per pig can remain the same.

When the cable has reached its end position the pigs are removed from the cable. To reach the rear pig, the duct must be opened at the location of the rear end of the cable. This could also serve as an exhaust for the water for the next cable, although with a 2-pig installation the duct could also be closed again with the water coming out at the front of the first cable again, because the water can flow freely over the first cable (when the pigs of the first cable have been removed the pressure resistance over this cable has dropped). In order to be able to splice the second cable to the first, some overlap is useful. For this a temporary duct extension can be made at the splice location. Bypassing water to the front of the first cable is still possible, but now requires special temporary duct connections.

TESTS

Different tests have been done on the WaTuCab method. A test for “flowing cable to desired location” is in preparation. First tests have been done on functioning of the Multi-Pig.

Test field St. Etienne du Grès

At our facilities in St. Etienne du Grès, a test circuit of a 976 m PVC duct of 160/152 mm has been buried in the ground. This circuit has been built in 4 loops, contains 14 bends of 90° and 3 siphons.

For validation purpose, 1 km of 82 mm 90 kV cable, with 1000 mm² aluminium core and weight of 68 N/m, has been successfully placed in the above described test circuit using the WaTuCab method [1]. Furthermore said cable has been placed and removed several times (for tests and demonstration purpose). Installation forces exerted on the cable were 6000 N for pulling and 7000 N for pushing, respectively.

In the above described test circuit a test is planned for this summer to evaluate the free flowing of the cable. For this a slightly larger test cable (89 mm, 84 N/m) with a length of 700 m will be installed first with the WaTuCab method and after that flown loose from the installation equipment.

Tests Multi-Pig

Fig. 8: Experimental setup to test grip Multi-Pig

The Multi-Pig was tested on gripping performance on the cable jacket using a Zwick test bench, located at the Nexans facilities in Cortaillod (CH), see Fig. 8. For this a 400 mm specimen of a 63 mm energy cable with HDPE jacket was used. The dividable Multi-Pig was mounted on this specimen and then the whole was put in the test bench. Here the pig was placed on a metal tube, sleeved around the cable, and the test bench pushed onto the cable surface from above. This made the conical teethed grip half-rings locking onto the cable jacket. The test was done during 15 minutes and up to 5000 N. After setting of the grip to the cable jacket, the grips really locked. The relaxation path (pressing of the rings into the jacket and moving into the conical part of the pig) for 5000 N was less than 0.2 mm in the last 10 minutes. There was no indication that the grip slips, as can be seen in Fig. 9, where the marks after 15 minutes at 5000 N are only small and not ”smeared”.

The test was repeated with the test bench pushing onto the surface of the copper cable core only, by means of a 25 mm metal cylinder (this is in fact the situation shown in Fig. 8). This was to test whether the jacket gripping force could be transferred to the other cable elements, without internal slipping (damage) of the cable. Above 4500 N slip occurred between the cable´s copper wire shield and its interior. Once this damage was done the slipping also occurred at 4000 N. At 3000 N no slipping occurred anymore, as was demonstrated in a test lasting 60 minutes, with a relaxation of less than 0.05 mm during the last 30 minutes, see Fig. 10.

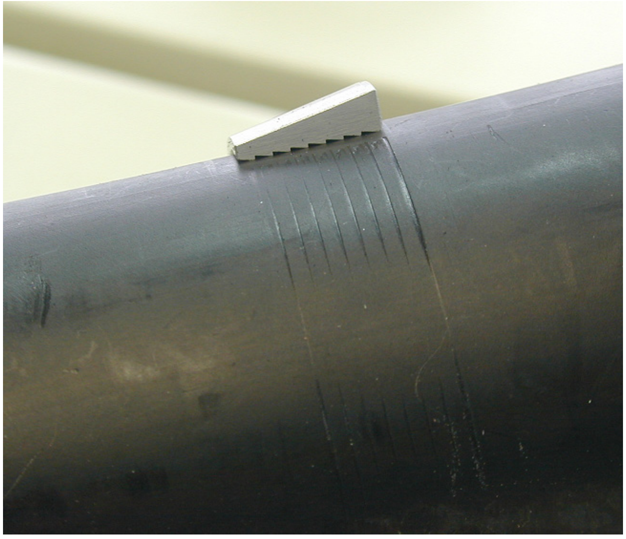

Fig. 9: Marks on cable jacket after 5000 N gripping

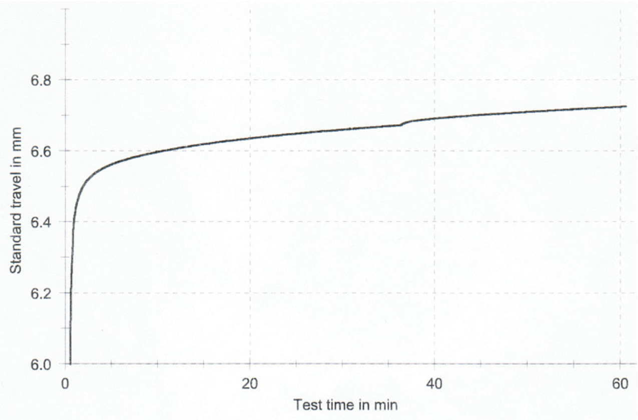

Fig. 10: Relaxation during pressing on cable core with 3000 N after pressing on whole cable with 5000 N

As the duct for which the tested Multi-Pig was made has an internal diameter of 109 mm (123 mm outer diameter), the force of 3000 N is equivalent to a pressure over the pig of 4.8 bar (note that only the annulus between duct and cable contributes to the force on the pig). This is amply sufficient for economical use of the pig method, see example of 3 pigs.

Tests have been planned to investigate at which force internal slipping of the cable elements occurs for longer cable specimens. Although not needed for the Multi-Pig method, it is interesting to know this value for anchouring the cable ends on its jacket to balance thermal expansion effects in ducts with smaller diameter than used today. This would allow for much less costly installation.

Tests with water pressure, measuring the pressure over the Multi-Pigs as a function of the water flow, and induced propelling forces, are planned before the conference. Results will be given during the conference.

PROJECTS

Several floating and WaTuCab projects have been done [1,6]. In this paper a list with floating achievements and a typical example of a WaTuCab project are given.

Floating installations

Floating is well known for the long lengths that can be reached, see impressive “one go” records in Table 1.

Table 1: Floating distance records

Cable (mm)	Duct ID (mm)	Distance (km)
12	41	10
11	33	9.5
2 x 13	41	5

WaTuCab installations

In this paper only one example is given of a WaTuCab installation (for more projects see [1]). A high voltage 72 mm 90 kV cable with 630 mm^2 aluminium core and mass of 4.9 kg/m has been installed in a 160/132 mm HDPE duct with the WaTuCab method. Section lengths achieved ranged from 1.8 to 2.3 km. In total over 18 km of cable was installed.

Fig. 11: WaTuCab installation of 72 mm 90 kV cable (630 mm^2 Al core) into 160/132 mm HDPE duct

CONCLUSIONS

An overview of current techniques to install cables in ducts has been given in this paper. A new idea with Multi-Pigs that share the pressure drop, has been described. Here the advantages of floating and the WaTuCab method are combined, increasing installation length considerably, while forces exerted on the cable remain small. First tests, on the Multi-Pig itself, have been done and look promising. Also a new idea to let the cable go with the flow, loose from the installation equipment, has been described. For this the cable is propelled by at least 2 pressure sharing pigs. This is especially useful in trajectories with places with difficult access for installation equipment and cable drums. A test with this method is planned this summer.

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