Available online at www.sciencedirect.com

ScienceDirect

Procedia Technology 22 (2016) 637 – 644

Procedia Technology

9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015, Tirgu-Mures, Romania

Study on Optical Fiber Insertion in Underground Telecommunication Networks Using Hydraulic Similarity

Mircea Grigoriu[a], Marius Constantin Popescu[b,]*

[a]*University Politehnica Bucharest,313, Splaiul Independenței, Bucharest,Postcode 060042, Romania*
[b]*Western University of Arad, 94-96 Revolutiei Blvd., Arad,Postcode 310025, Romania*

Abstract

The European regulations require a new approach of cities facilities networks, including the communication ones. In this respect, the communication providers generalize the underground networks, following the streets trails. The transmission support consists in a network of tubes, protecting a number of micro-tubes/microducts, which protect the real transmission facilitators made by optical fibers. Presently, the producers of this type of devices promote special norms of information on characteristics and installation of the product, but there are not reliable accepted standardized methods for optical fibers insertion in pre-installed micro-tubes/microducts and for the devices forces computation, necessary for underground communication networks. The micro-tubes are already installed in the protection cables and together are buried in the ground on different routes. It appears the necessity to introduce the fibers in the micro-tubes in this situation. Generally, it is a significant difference between the practical reality and the producers norms and indicators. In order to explain this situation, and considering the optical fibers dimensions, and the necessity to insert the fibers using specific lubricants, the paper propose a similarity model of the optical fibers insertion in the micro-tubes with the hydraulic model of laminar incompressible fluids flow in parallel or concentric micro- layers. In this phase, there are presented the results of experimental measurements and tests on in situ networks, composed by different types of materials and lubricants, as support for the hydraulic similitude.

Peer-review under responsibility of the "Petru Maior" University of Tirgu Mures, Faculty of Engineering

Keywords: optical fiber insertion; experimental results; friction loss; hidraulic hypothesis;

* Corresponding author. Tel.: +4-072-132-9997; fax: +4-021-402-9865.
E-mail address: grigoriu.mircea@gmail.com

Peer-review under responsibility of the "Petru Maior" University of Tirgu Mures, Faculty of Engineering
doi:10.1016/j.protcy.2016.01.133

1. Introduction

Nomenclature

τ	longitudinal effort within the fluid layers
u	velocity of the fluid
δ	total transversal dimension of the fluid layer
du	velocity variation across the transversal dimension
dy	transversal dimension infinitesimal variation
μ	dynamic viscosity
h	friction loss
K	constant
l	pipe length
D	pipe diameter
g	gravity acceleration
λ	friction losses coefficient of Darcy

More and more telecommunication operators are forced for different reasons (network expansion, specific EU or local regulations which introduce interdictions for aerial cables, aesthetics) to replace aboveground telecommunications networks with underground fiber optic networks. In this context, the telecommunication operators demand to the producing companies to supply new materials and equipment (fibers, micro-tubes, specific lubricants and installation equipment) capable to be used in extended underground networks. It is important that fibers should be introduced in the micro-tubes after these are already buried.

Presently, there are no technical specifications imposed concerning the micro-tubes laying and the optical fiber insertion, and also on the specific materials and equipment. The telecommunication services providers orders to the producers communications products only in terms of micro-tubes dimensions: diameter and length, without any control of the micro-tubes position inside the protection cables. But, obvious, this type of condition becomes essential for the natural process of network installation. Producers supply special equipment to introduce (under pressure of air or hydraulic support) the fibers, but they are not able to compute the necessary force to be provided for a specific diameter and length, in special condition of lubrication and considering the real fibers position in the tubes.

The problem consists in the hydraulic losses of energy arising between the optical fiber and interior micro-tubes evaluation, considering specific condition of each micro-tube.

The principal types of friction losses identified are:

- Longitudinal (linear) losses, caused by the linear fiber displacement along the micro-tube
- Singular (local) losses, caused by the changes in direction or section of the micro-tube, guiding the fibers.

The material locations of the local losses are called *singularities*. There are represented by deviations from the perfect linear position, which differs from a micro-tube to another. Their effect is a specific additional loss of energy, which values could be important, comparable to the linear losses themselves.

From the operation point of view, the singularities can reduce the signal efficiency, but this is not the paper subject. For a given micro-tube parameters (diameter and length), the number of singularities are significantly reducing the specific insertion equipment efficiency. The equipment providers offer technical specifications for a proper working, considering the micro-tubes absolute perfect as dimension and linear direction. From the energy loss point of view, the producers offer some diagrams of the effective fibers insertion lengths for a given force provided. Basically, the technical specification inform on the optimum distance to introduce the optical fiber [1].

Taking into consideration the extreme small amount of the fibers diameter and extreme thickness of the layer of lubricant, the fibers displacement along the micro-tubes walls can lead to a similarity model with the hydraulic model of laminar incompressible fluids flow in parallel or right or curved micro-layers for the infinitesimal layers of incompressible fluid displacement along the solid walls delimitating the fiber.

2. The real telecommunication network behavior

The experiments were made on a real network, owned by an important telecommunications services provider. The network signal wiring consists of protection cable for optic fiber PEHD (High Density Polyethylene) DN (nominal diameter) 50x3 mm, with 10 optic-fibers DN10x1 mm, located on various routes. Telecommunication operators, intending to introduce the optical fibers in the micro-tubes for the usual distance, find a significant difference between the length predicted by the producer and the real situation [2]. This dysfunction produced both economic and technical negative effects. From economic point of view, it arise the necessity to multiply the visitation sewage rooms, where the optical fibers are coupled, in order to continue the network.

The technical deficiency consists in a significant reduction of the signal quality. It cannot be observe the fibers direction along the burred tubes, but it can be noted a significant fibers deviation in these sewage rooms. It can expect such a deviation from the perfect parallel direction of the fibers, along the burred tubes, also. It could be only curvatures or inflections, but it is obvious the tubes are not perfect right oriented. A supplementary deviation appears just in the sewage rooms, where the fibers are coupled.

The effect of these deviation, inflections and curvatures (even obscurations) of the fibers lead to an energy losses during the fibers introduction in the micro-tubes. Figure 1 presents some twill of the micro-tubes in an operation field.

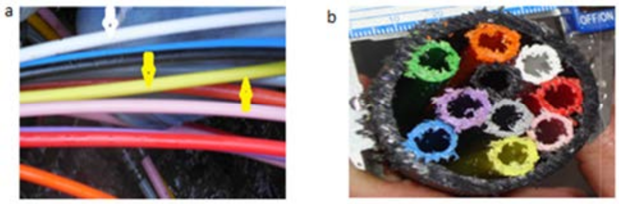

Fig.1. (a) existing deformations along the microducts, (indicated by arrows); b) bonding of microducts to the protective tube.

Since, the networks installation depth is between $4x10^{-1}$ m and 1 m above ground level, there is no danger from external causes crushing optical fiber. Then, the only reason of the additional energy losses during the fibers intrusion within the micro-tubes is the distortion of the fibers direction. The lack of strict technical specifications requirements in terms of placement the tubes and blowing the optical fiber leads to ad-hoc procedures, which could produce deviation and deformations of the micro-tubes, with effects on the optical fibers trajectory.

Even the whole network is buried and could not be visited, in the sewage rooms the micro-tubes and the fibers are apparent and can be seen. An in practice visual observation of the micro-tubes at the sewage rooms reveals:

- Mechanical deformation, that could be considered manufacturing defects [3,4];
- Points of bonding of micro-tubes to the protective tube, that can be caused by installation process;
- Longitudinal and inflection curvatures that can be manufacturing defects or can by caused by the installation process.

Manufacturing process consists in the whole production technological process, completed by the packaging and transportation processes. Manufacturing defects of the delivered products by the providers can be accumulated from initial material supplying, to the final transportation to the installation point. According to DIN 8074, the maximum deviation from the standard size of micro-tubes diameter is 10^{-3} m.

Installation process is represented in the first stage by micro-tubes introduction in the protective tube and the protection tube lying in the ground, and in the second stages by the optical fibers introduction in the micro-tubes itself.

In practice, they have encountered situations when the optic fibers are:

- Introduced for a much shorter distance then it is mentioned in the manufacturers prospects (or with a supplementary effort).
- Completely stopped without joining the micro-tube end.

3. Experimental results and discussions

3.1. Equipment and procedures

Following the manufacturers' instructions for optical fibers insertion in the preinstalled micro-tubes, there were carried out in situ experimental for different types of energy supplying equipment, number of fibers and lubrication materials, and obtaining different maximum distances insertion. In the performed experiments on underground telecommunication network described above was observed that, although energy supplying (pumping) equipment (CBS, Cable Blowing Machine) [5] and Microflow [6] have worked to maximum performance, they cannot achieve significant distances to introduce the optical fiber.

For instance, the Microflow technical book presents a micro-tubes blowing distances of 3.5x103 m for the equipment utilized in situ, and the experimental results are significantly different. Moreover, Microflow device is based on a modern technology (blowing compressed air) for overcoming the friction losses.

Mechanical deformation existing along the micro- tubes may introduce the supplementary fluid friction forces which oppose to the optical fiber insertion in preinstalled micro-tubes. In other words, the amount of engine effort developed by the blowing machine, from a certain distance, becomes insufficient for the purpose definite in the manufacturer technical book. The effect is that the machine stops the operation of blowing the optical fiber, in order to avoid fibers of machine deteriorates due to mechanical stress.

3.2. Experimental results

Previously to the real experiments, there were blown (pumped) a „witness", represented by a small piece of optical fiber (of about 200 mm), which achieved the bottom of each tested micro-tube, in order to demonstrate that the micro-tube have the appropriate dimension and l lubrication and is prepared for operation.

The figures 2, to 5 presents the lengths of fibers installation obtained, using the appropriate recommended in the technical books procedures, materials and equipment [7], as follows. Optical fibers type Prysmian have 96 wires, with diameter of 6.5x10-3 m. Optical fibers type Nexans have 72 wires, with diameter of 5.5x10-3 m.

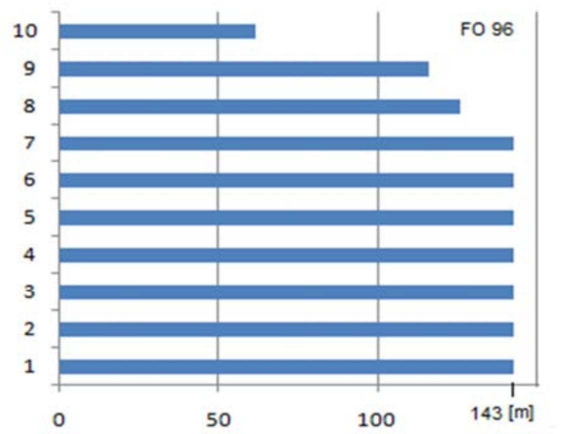

Fig.2. Maximum blowing distances for 10 optical fibers type Prysmian, at 143 m distance, using a CBS machine..

Fig.3. Maximum blowing distances for 10 optical fibers type Nexans, at 143 m distance, using a Microflow machine

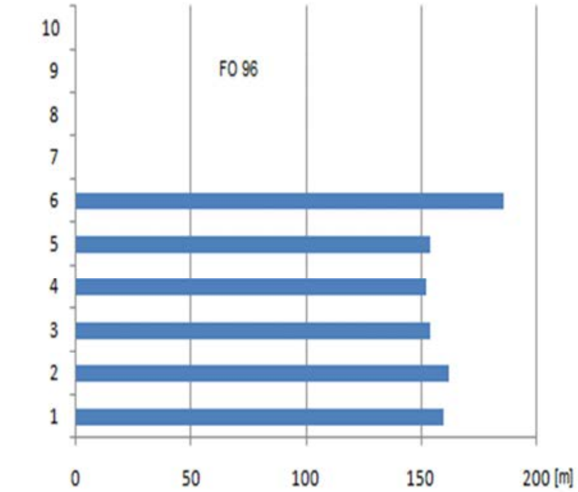

Fig.4. Mmaximum blowing distances for 10 optical fibers type Prysmian, through a tube of 568 m, at 143 m, 22 m, 49 m, 67 m, 97 m, 80 m and 110 m distance, using a Microflow machine

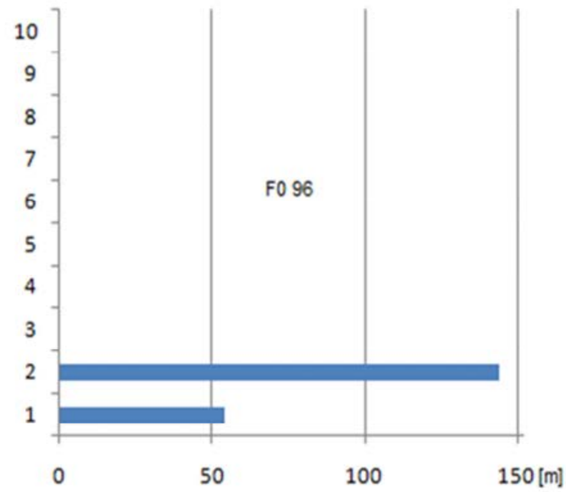

Fig.5. Mmaximum blowing distances for 2 optical fibers type Nexans, through a tube of 568 m, at 143 m, 22 m, 49 m, 67 m, 97 m, 80 m and 110 m distance, using a Microflow machine.

3.3. Discussions

Along the micro-tubes placed in a protected tube, placed or not by a specific canalization, the optical fibers deviation could not exceed important values, because an important deviation lead to a significant distortion of the signal transmission, even for short distances [8].

Along the micro-tubes placed in a protected tube, placed or not by a specific canalization, the optical fibers deviation from the right blending may occur due to:

- Changings of the route of the network itself in different directions, along the route of the concrete conditions of the location
- Changings of the route in different directions to bypass certain other supping networks or others obstacles
- Interweaving of the micro-tubes during the ensemble manufacturing and installation, etc.

It is obvious that the fibers deviation could not exceed important angular values, which are avoided by the network designer from the beginning, but summarizing their effects, the energy losses for optical fibers insertion in the micro-tubes become important. Even the network designers avoid this kind of direction changings that could lead to significant distortion of the signal transmission. But, there are at least two positions where the significant deviation of the fibers could not be avoided, at the top and the bottom of the tube, between the sewage rooms. In this location, are necessary angular direction changings of about 90^0. These singularities have an important effect, also.

Generally, the interweaving of the micro-tubes during the ensemble manufacturing and installation could not be predicted with an accepted precision, and their effects on the optical fibers insertion could be considered only by statistic methods [9]. But, the designed changings of direction are known, and their effects to the optical fiber insertion can be estimated by computation and similarity methods [10].

4. Similarity model proposal

The optical fibers diameters are about of 1 mm, or less and the distance between the fibers and the micro-tube wall is about the order of fractions of millimeters. In these conditions, the viscous lubricant movement can be assimilated to the displacement of a lubricant film of incompressible fluid between two plane surfaces in relative movement. This is the Newton's model, considered for the dynamic viscosity definition. Newton imagines a fluid layer of infinitesimal thickness, positioned between two parallel surfaces, moving in a relative displacement one to other. The fluids adhere to the solid surfaces. The same situation meets in the case of a flow through a circular pipe.

"The velocity gradient occurs because in pipe flow, the velocity of the liquid varies radially at any cross section of the pipe. (…) The liquid molecules adjacent to the pipe wall are at rest or have zero velocity. The liquid molecules that are farthest from the pipe wall-namely, at the center of the pipe-are moving at the maximum velocity. Thus, a velocity variation or a velocity gradient exists at any cross section of the pipe (…) Newton's law states that the shear stress τ between the adjacent layers of the liquid in motion is related to the velocity gradient *du/dy* as follows

$$\tau = \mu \frac{du}{dy} \tag{1}$$

The constant of proportionality is the absolute (dynamic) viscosity of the liquid, μ" [7].

For practical reasons, considering the extreme order of the lubrication fluid film thickness, which is divided in infinitesimal layers, it is acceptable to suppose that the velocity gradient is linear, and the effort between fluid layers is constant, so

$$\tau = \mu \frac{u}{\delta} \tag{2}$$

considering the maximum velocity and the total length of the fluid flow cross section.

It is to observe the similitude between the classical hydraulic (hydrostatic) machineries and the specific equipment used to introduce the optical fibers within the micro-tubes of the communication networks. The specific equipment are creating a overpressure in order to push the optical fibers along a film of fluid, which ensure the lubrication between the fiber and the tube wall The equipments are coupled by electrical motors, in the same way the hydraulic machineries are [11].

The two types of equipment are:

- CBS pneumatic gears, working as hydrostatic blowers/compressors;
- Microflow hydraulic gears are working as hydraulic pumps.

Optical fiber could be assimilated with a very narrow annular flow (elementary thread) of incompressible fluid, which is flowing within the micro-tube.

The equipment moving components are producing the necessary energy for the optical fibers transport with a reasonable efficiency, similar to the classical hydraulic machineries efficiency. The hydraulic machineries, similar to the equipment in discussion are of hydrostatic type, such as gear pumps or compressors. The hydraulic machineries efficiency components are:

- volumetric efficiency, considering losses of fluid through the machines seals;
- hydraulic efficiency, considering the hydraulic frictions during the working fluid movement within the machines components;
- mechanical efficiency, representing the hydraulic frictions of the sealing fluid, within the mechanical components of the machines (training and support pieces of the machines, in particular bearing and sealing bodies), outside the hydraulic body, which contain the working fluid.

Generally, comparing to other types of hydraulic machines, the hydrostatic machines have a high volumetric and a low mechanical efficiency. Their hydraulic efficiency depends significantly to the specific type of machines.

For the optimum field of operation, the dependence curve of head and capacity of the hydrostatic machines can be approximated with a vertical line.

A similar situation can be identified at the pusher equipment of the communication networks. The optical fibers are solid bodies, then a theoretical volumetric efficiency is the unit itself.

The mechanical efficiency is low because the driving and support system is similar to the hydrostatic machines.

The hydraulic efficiency is similar to the hydraulic machines, because the friction losses have a similar nature.

The efficiency is influenced by the fluid nature (gas or liquid), but the tendency are similar. In the hydrostatic compressors situation, the efficiency is influenced by the compression phenomena, but the tendency are similar to the pushing equipment using air as working fluid. For both for the hydrostatic hydraulic machines and the pushing equipment, the necessary operation pressure is composed (demanded) by the resistant pressure of the installations.

The maximum operation pressure both for the hydrostatic hydraulic machines and the pushing equipment is the maximum pressure for their correct operation. If the resisting pressure exceeds the maximum admitted pressure of the machines, they should stop operating or will suffer damages. For a correct understanding of the hydraulic machineries operation, it is important to take into consideration the assemble of machine and the installation function [12].

The pushing equipment operation study could not be imaged without considering operating in anssable with the micro-tubes and the optical fibers of the network [13].

According to the Darcy equation [14],

$$h = \lambda \cdot \frac{l}{D} \cdot \frac{u^2}{2 \cdot g} \tag{3}$$

from the mentioned installations point of view, the friction losses through the pipes depends on the pipe lengh, pipe diameter, square of the speed, gravity and a coefficient depending to the walls delimiting flow quality and the flow aspect. The Darcy coefficient depends on the type of fluid displacement according to the Nikuradse low [14].

The necessary energy for fluid transportation through the pipes depends directly by the friction losses. In a similar way, the necessary energy to push the optical fiber depends on the friction losses in the lubricant fluid. An increase of the fluid flow velocity is followed by an increase of the hydraulic losses through the installations pipes. Similarly, in increase of the optical fiber velocity through the micro-tubes lead to an increase of the necessary effort caused by an increase of the friction losses in the lubricant fluid.

A simplified equation for friction losses through the pipes is [15]

$$h = K \cdot Q^2 \tag{4}$$

but, it could be used in moderation in the similitude proposed study and after a other experiments.

Considering the pushing equipment power limitation, it could be demonstrate a correlation between this parameter and the maximum installation friction loss supported by the equipment, which is correlated to the maximum distance of optical fiber insertion in the micro-tube [16]. Discussing the stability of the equipment-installation operation stability, it could be considered the similitude with the pumping systems (composed by a hydraulic machinery and an installation) stability.

5. Conclusions

The experiments developed in different conditions and operating with similar materials and equipment, but provided by different manufactures and having different characteristics, demonstrate that in situ conditions differ from the special conditions of the laboratories where the optical fibers and the micro-tubes are tested by the manufacturers.

Considering there are not specific standards or general accepted norms for the optical fibers insertion in the communication networks computation, it rise the necessity of a practical method, in order to facilitate a correct design of the sewage rooms positioning and the hole network configuration.

The optical fiber insertion in the micro-tubes of the network is made using a lubrication fluid and a pressure machine, and the opposition force represents the result of the total fluid friction stress (losses) in the fluid, during and along the optical fiber inside the micro-tube. Because the micro-tube is not perfect linear, there are identified two types of friction losses

Longitudinal (linear) losses, caused by the linear fiber displacement along the micro-tube

- Singular (local) losses, caused by the changes in direction or section of the micro-tube, guiding the fibers.
  The manufacturers consider in their tests only the linear losses.
  The local losses have different causes:
- Changings of the route of the network itself in different directions, along the route of the concrete conditions of the location
- Changings of the route in different directions to bypass certain other supping networks or others obstacles
- Interweaving of the micro-tubes during the ensemble manufacturing and installation, s.o.

In the evaluation process of the friction losses, it is practical impossible to compute the losses caused by the interweaving of the micro-tubes, except by a statistic methods. Although, the other losses could be computed using similarity method of evaluation, based on the Newton theory of the viscous fluid flow.

References

[1] Kaminow, I, Tingye Li, Willner, A. Optical Fiber Telecommunications, Elsevier Inc., 2008, p.325.
[2] Popescu M.-C. Technical expertise judicial report, Cluj Napoca Court Low, Cluj Napoca, 2015, p.3-17.
[3] Jones, R.M. Deformation Theory of Plasticity. Bull Ridge Corporation, 2008, p. 263-278.
[4] Rees, D. Basic Engineering Plasticity: An Introduction with Engineering and Manufacturing Applications, Butterworth-Heinemann, 2006, p.367-395.
[5] *** Cable Blowing Machine, 2014, p.3-5.
[6] *** Fremco Miniflow Rapid, 2012, p.1-8.
[7] Shashi Menon, E., Menon, P. Working guide to pumps and pumping stations, Calculations and simulations, In: Gulf Professional Publishing in an imprint of Elsevier, Burlington, MA, 2010, E-Publishing Inc; 1999. p.7-8.
[8] Hecht, J. City of Light: The Story of Fiber Optics, Published by Oxford University, 2004. p.23-26.
[9] Wang, Q., Gerald Farrell, G., Yan, W. Investigation on single-mode–multimode–single-mode fiber structure, Journal of Lightwave, Technology, Vol.26, Issue 5, 2008. p.512-519.
[10] Essiambre, R.-J., Kramer, G., Winzer, P. J., Foschini, G. J., Goebel, B. Capacity limits of optical fiber networks, Journal of Lightwave, Technology, Vol.28, no.4, 2010, p.662-701.
[11] Grigoriu, M. Pumps and pumping installations (romanian language), Printinghouse Printech, Bucharest, 2006, p.281 – 282.
[12] Traxler-Samek, G., Schwery, A., Zickermann, R., Ramirez, C. Optimized Calculation of Losses in Large Hydro-generators using Statistical Methods, Springer Netherlands, 2006, p.13-23.
[13] Sumereder, C. Statistical lifetime of hydro generators and failure analysis, Dielectrics and Electrical Insulation, IEEE Transactions on , Vol.15, Issue 3, 2008, p.678 – 685.
[14] Flore, J., Panaintescu, V. Fluid Mechanics (romanian language), Didactic and Padagocic Printinghouse, Bucharest, 1979, p.339 – 342.
[15] Covas, D., Stoianov, IN., Mano, JF., Ramos, H., Graham, N., Maksimovic, C. The dynamic effect of pipe-wall viscoelasticity in hydraulic transients. Part II— model development, calibration and verification, Journal of Hydraulic Research Vol. 43, No. 1, 2005, p. 56–70.
[16] Popescu, M.-C. Telecommunications (romanian language), Universitaria, Craiova, 2008, p.95-101.