Calculation of forces in cable during installation in pipes for different methods

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ABSTRACT

A complete theory is given of force build-up in cables pulled in pipes, beyond "classic" Rifenburg equations, including large radius bends and/or pushing the cable, following the outside facing wall of the bend. Also 3D-bends are treated. This is used in software, where besides gravity friction and capstan effect also "waving" the cable during pushing and the effect of cable stiffness in bends and undulations in the pipe are taken into account. Not only pulling and pushing, also other installation techniques are evaluated, like those making use of fluid propelling (blowing and floating).

KEYWORDS

Cable; Pipe; Pulling; Pushing; Blowing; Floating; WaterPushPulling; FreeFloating; Undulations; Horizontal-; Vertical-; 3D-; Bends; Capstan effect, Cable stiffness.

INTRODUCTION

A complete theory is given of the force build-up in cables pulled in pipes. The well-known "classical" equations of Rifenburg et al. for pipes with horizontal and vertical bends, taking into account gravity friction and capstan effect, are reviewed. An extension of the theory has been derived for bends with large radius (like in HDD drills) and/or for the cables being pushed. In both cases the cable might be pressed against the outside facing pipe wall. Furthermore, bends are treated which are neither in a horizontal, nor in a vertical plane. Analytic equations have been derived for the total bend angle related to the entry and exit slope and to the angle in the horizontal plane. Analytical calculation of force build-up is no longer possible in this case and must be performed numerically. Therefore, a software program was developed to treat those 3-dimensional bends.

The software program takes more effects into account than just 1) gravity friction and 2) capstan effect, namely: 3) additional friction in bends and undulations in the pipe due to cable stiffness and 4) additional friction during pushing due to "waving" of the cable (also related to cable stiffness). Furthermore, the software can evaluate installation techniques other than winch pulling. Not only pushing, also pushing/pulling, and new techniques as described below.

The action of (high-speed) fluid distributed propelling forces can also be calculated. With air as fluid the cable blowing technique is included, a method widely used for smaller cables, like optical cables. Water as fluid is also suitable for energy cables, where the floating technique can be used for pipes with internal diameter up to the order of 100 mm. Here there is benefit from the reduced effective weight of the cable in water due to buoyancy. For larger pipes (and cables) a pig is used at the front end of the cable. The technique is then called waterpushpulling and can be used for any cable and pipe size. Advantages are that no winch line needs to be installed, all material and operation is at one side of the track and forces (axial and sidewall) are lower than with traditional winch pulling. The software can calculate it all. Last but not least also freefloating can be evaluated, a technique where the cable, once installed by waterpushpulling, can be transported further to any location, loose from the machine, like "tube post". Some examples of real installations will be given, with evaluation.

CALCULATION PULLING (PUSHING)

Calculations will be done for straights and different bends.

Straight section

The coefficient of friction (COF) is defined as the force to move a body over a surface divided by the normal force between that body and surface. When pulling a cable into a straight and sloped pipe section (inclination angle α with horizontal, negative when downhill) the axial force dF to pull an infinitesimal length ds of that cable is given by [1,2]:

$$dF = \left[fW\cos\alpha + W\sin\alpha\right]ds$$

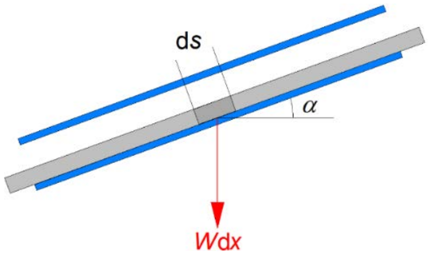

Fig. 1: Straight pipe (sloped) section with inclination (slope) with the horizontal α

Here f is the COF between cable and pipe and W the weight per unit of length of the cable. The term at the right side is the force needed to pull the cable to another elevation. Carrying out the integration it is found that the axial (pulling) force in the cable increases linearly along the pipe as a result of gravity friction (which is constant over the length). The axial force F_2 after pulling a cable over a length L with an axial force F_1 when entering the section is given by [1,2]:

$$F_2 = F_1 + \left(f\cos\alpha + \sin\alpha\right)WL \qquad [1]$$

The above friction is called gravity friction. If this was the only contribution to the axial force build-up in the cable very long pulling lengths could be achieved. However, already built-up axial forces in the cable in bends (and undulations) in the pipe are usually dominant and cause exponential force build-up, limiting cable pulling lengths.

Horizontal bend

When the cable is pulled through a bend in the pipe the friction is proportional to the already built-up pulling force. The harder you pull, the harder the cable is pulled against the inside facing wall of the pipe, with linear normal (radial) force density F_n (often erroneously called sidewall pressure or radial force), and the more friction is generated. The axial force will then increase exponentially, called the capstan effect. When gravity friction works together with this capstan effect, the formulas become a bit different.