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A NEW INSTALLATION METHOD FOR CONVENTIONAL FIBRE OPTIC CABLES IN CONDUITS

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Abstract

A new technique for the installation of conventional fibre optic cables in commonly used conduits using the viscous flow of air is decribed. Blowing experiments have been carried out, using different cables, conduits and lubricants. For better understanding also pulling experiments with conduits having different tortuosities and supporting laboratory experiments have been performed. The non linear pressure decay in the tube in which the cable is blown is experimentally verified. Furthermore a simple experiment for measuring the cable stiffness is described. With one installation unit 1 km fibre optic cable can be installed with speeds up to 1 m/s. Even 36 right angled curves in the conduit can be passed. In less than one hour a reel with 2100 m fibre optic cable can be installed using the installation units in cascade, without synchronisation problems. This means that longer cables can be installed in the future. The described method is very simple because for instance no pulling ropes have to be installed. Furthermore the cable strain can be kept low. Halfway 1988 1000 km fibre optic cable have been installed in the public network of the Netherlands using the described method, considerably saving man and time.

Introduction

The old installation method

In many countries fibre optic cables are pulled in pre-installed conduits. The pulling force is fully concentrated at the cable end there. It is well known that with this technique an exponential build up of the pulling force occurs due to the cable tension, especially on tortuous routes [1]. In some countries conduits with an inside diameter of only 26 mm (cheap!) are used. The only disadvantage of these conduits is the fact that without special precautions the windings give rise to a quick build up of the pulling force, necessary to install the cable (appendix 1). To reduce excessive forces on the cable, capstans are used for intermediate assistance. For the small diameter conduits, as are used in the Netherlands, the most economic distance between those capstans is 175 m for the installation of a reel of 2100 m fibre optic cable.

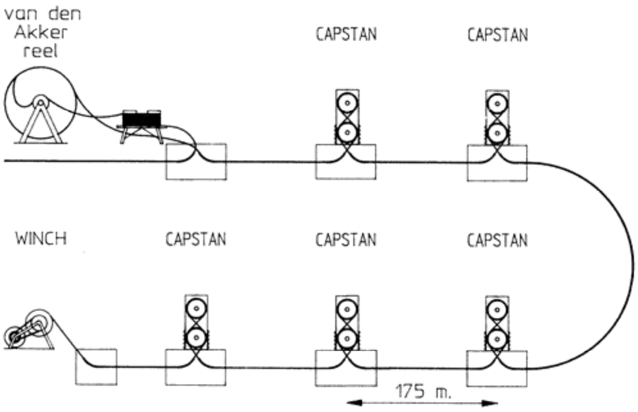

figure 1: pulling 1050 m of fibre optic cable with the help of capstans and a bufferreel (Netherlands PTT, before 1988)

In figure 1 the old installation method, as formerly used by the Netherlands PTT, is shown. The reel is placed halfway. In three 175 m sections the pulling rope is installed by means of a shuttle driven by compressed air. The cable is pulled with a winch assisted by two capstans. Next the winch is placed at the far end of the traject and the pulling rope is installed in the next three sections. Now the pulling takes place with the help of five capstans. When the first 1050 m is installed the rest of the reel is rewound on a special buffer ("van den Akker") reel. Now the next 1050 m can be installed in the same way as described above (this part of the installation is shown in figure 1).

It is clear that this installation method is man and time consuming. For this reason and for the need to install cable lengths longer than 2100 m in the future, another installation method is searched for.

The new installation method

The previously mentioned exponential build up of the pulling force can be prevented when the cable tension is kept low. This can be achieved when the friction between cable and conduit is compensated locally, i.e. when the pulling force is distributed along the whole cable length. In that case each conduit can be considered straigth for flexible cables. Cassidy et al. [2] have found an elegant method for reaching this. They blow very small, flexible and lightweight fibre members (designed for use inside buildings) into conduits without the use of a shuttle at the cable end. The force F/l exercised on the cable per unit of length, when the pressure drop at the cable inlet is compensated mechanically, can be written as [2]

$$F/l = -\frac{dp}{dz} \cdot \pi\, r_{cab}\, r_{cond} \qquad (1)$$

where dp/dz is the pressure gradient along the conduit, and r_{cab} and r_{cond} are the outer radius of the cable and the inner radius of the conduit respectively.

In this contribution a scaling up of this method is described which can be used for conventional fibre optic cables. The cables do not need to be flexible, in fact a certain stiffness is advantageous. In that case the cables can be pushed over a certain distance which is a useful assistance because of a relatively low pressure gradient in the first part of the conduit [3]. In appendix 2 measurements have been carried out in order to verify the non linear pressure decay in the conduit. The stiffness of the cable must be such large that pushing of the cable causes not too much buckling. On the other hand the stiffness of the cable may not be too large because then the cable experiences too much friction with the conduit in curves and windings of the conduit. A good choice for the stiffness B of the cable can be derived [3].

$$\frac{8}{\pi^3} \cdot \frac{a(P/4)^2}{A} \cdot F_p \lesssim B \lesssim \frac{2}{3}\,\frac{W(P/4)^4}{A} \qquad (2)$$

where W is the cable weight per unit of length, A and P are the (estimated) amplitude and period of the (sine shaped assumed) windings in the conduit respectively, Fp is the pushing force and a is the half free radial space (r_{cond}-r_{cab}) of the cable in the conduit. This relationship has of course only sense when Fp may have values such that it effects the installation of the cable. Most fibre optic cables forfill inequalty 2. In appendix 3 a simple experiment for measuring the cable stiffness is described. It can be shown [3] that for a situation which is typical for the cable and duct combination of the Netherlands PTT, the additional pushing force can double the installation length that can be reached by cable blowing.

In figure 2 the new installation method is shown. The 2100 m reel is placed at one end of the traject. Four special developed dismountable cable injection units can operate in cascade with a most economic intermediate distance of 525 m and the whole cable reel is installed in this simple single operation, eliminating the installation of pulling ropes and the need for a bufferreel.

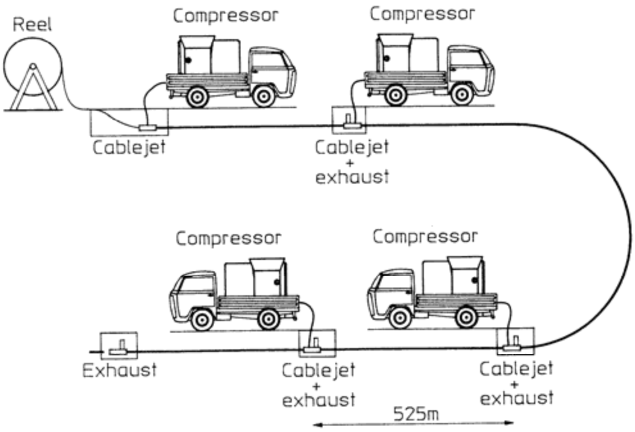

figure 2: Blowing 2100 m of fibre optic cable using the injection units in cascade (Netherlands PTT, after 1987)

The injection unit

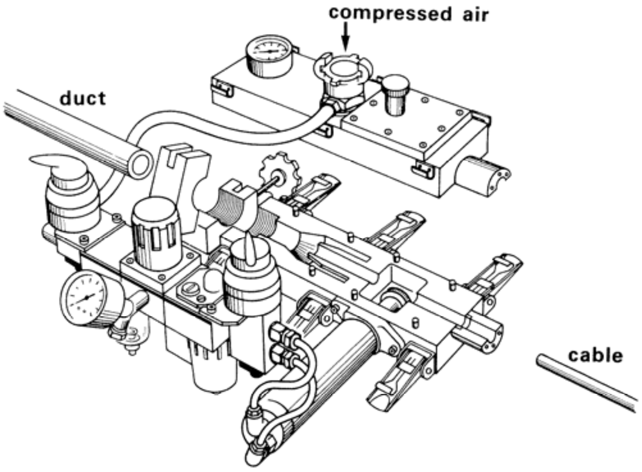

figure 3: The first prototype of the injection unit

A special cable injection unit[6] has been developed and is shown in figure 3. The airflow and all the other functions can be supplied by a simple compressor (75 l/s, 8 bars), which was formerly used for the installation of the pulling rope. The unit consists of two parts that can be mounted together in such a way that it will be possible to use several units in cascade. The compensation of the pressure drop along the cable inlet [2] and the additional pushing force [3] are supplied by grooved hollow wheels driven by a pneumatic motor. These wheels are pushed against the cable by means of pneumatic pistons (not shown in figure 3) so that small variations in cable diameter can be tolerated. The pneumatic motor can be stopped, just by holding the cable, also when lubricants are used. This is a great advantage when the cable injectors operate in cascade. The installation speed is controlled by the unit with the lowest setting of the pressure regulator for the pneumatic motor. For protection of the injection units in cascade and for reasons of safety, a 'funnel' for the exhaust of the airflow (not shown in figure 3) has been developed for operation together with the injection units.

Results

It turned out to be possible to install cablelengths with a maximum of 1 km in conduits with an inner diameter of 26 mm using one single installation unit, while speeds up to 1 m/s were reached when using standard cables. Using cables with ribbons on their jackets or 40 mm inner diameter conduits the performance even increases. For the latter application a compressor with a maximum pressure of 8 bars and a capacity of 130 l/s is needed, while for smaller conduits smaller compressors are sufficient. The independency of curves and windings in the conduit is clearly shown during a test in an extremely tortuous circuit. In this circuit, which has a length of 420 m and in which there are 9 right angled curves and windings equivalent to 27 right angled curves, a cable is installed using the described method.

Several lubricants have been tested for the blowing method as a possible alternative for paraffine oil. The lubricants, two types 2 and one type 3 (see appendix 1), gave rise to foaming, were dried by the airflow or caused the cable to 'stick' to the conduit wall because of their high viscosities. Pipe 3 with lubricant 4 (see appendix 1) gave satisfactory results, however, only 800 m was available as a testlength. Until now paraffine oil is the best solution. It is sufficient to pour about one liter of the latter in the conduit before connecting the installation unit. The paraffine oil will be distributed through the conduit by the airflow and the cable doesn't need to be lubricated.

In an experiment in which 500 m of 26 mm inner diameter conduit was already filled with a cable, an attempt has been made to install a second cable using the blowing technique. This installation was possible in the first part of the conduit but stopped after 280 m.

In the public network 2100 m fible optic cable can be installed in less than one hour using four installation units in cascade. Occasionally also cables with a length of 3150 m have been installed using the blowing method. Halfway 1988 more than 1000 km of fibre optic cables have been installed in the public network of the Netherlands using the described method, considerably saving man and time. The old pulling method has now been abandoned.

Conclusions

The blowing technique for the installation of conventional fibre optic cables as is described in this contribution is a quick and simple method, eliminating the extra step of installing a pulling rope. The cable strain is kept low during installation. Long lengths can be installed per installation unit in both straight and tortuous routes so that cheap conduits can be used without paying special attention to reduce the windings during the installation of the conduits. For lubrication it is sufficient to pour a small amount of paraffine oil in the conduit before connecting the installation unit while the cable doesn't need to be lubricated. The installation units can be easily used in cascade with intermediate distances only dependent on the properties of the cable, conduit and lubricant used, and almost independent of curves and windings in the conduit sections. There are no synchronisation problems when several units are used in cascade. This means that there is no limit for the cablelength that can be installed, so that longer lengths and hence less splices in the future are possible. The possibilities of the described installation method can further increase when special cables (optimised for blowing instead of pulling) and lubricants are used. It is possible to install more than one cable in a conduit (not necessary in the same time) for short distances. This might add some applications to the described method, such as local networks and unforeseen expansions of the trunk network.

Acknowledgements

The author wishes to thank C.L. de Jong and K.F. Betcke for the construction of the injection units and J.C. Veenis with his crew members for assistance with the field experiments.

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Appendix 1: The effect of conduit windings on pulling force build up

In order to calculate the effect of windings in a duct traject Buller's formula [1] is used in combination with a formula that gives the effective angle per unit of length θ_{eff}/l for a given conduit geometry [3].

$$F_2 = WR \sinh [f\theta + \operatorname{arcsinh} (F_1/WR)]$$

$$\theta_{eff}/l = 1/R_{eff} = 4\pi A/P^2 \qquad (3)$$

This formula gives the pulling force F_2 as a function of the force F_1 of the cable when entering the conduit at certain cableweight per unit of length W and bending radius of the conduit R. In the second part of the formula R_{eff} is an effective bending radius of a tortuous conduit with (sine shaped) windings of amplitude A and period P.

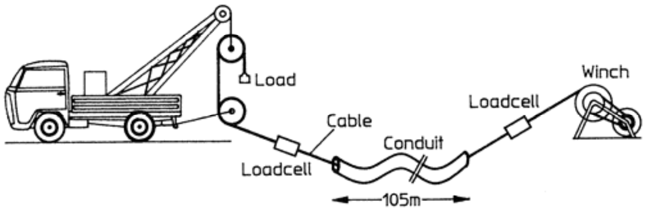

figure 4: Field experiment for measuring the effect of defined windings.

The formula which gives the effective tortuosity in an angle per unit of length has been verified in a field experiment with horizontally 'sine shaped' conduits (figure 4). Conduits with an inside diameter of 26 mm and a length of 105 m, having windings with amplitudes of 7.5 and 15 cm and periods of 2, 3 and 4 m were used. From the measured forces before and after the conduit in which the cable is pulled with a speed of about 20 m per min, the friction coefficients can be derived using formula 3.

P(m)	A(cm)	F(N) 10	20	30	40	50	100	150	200
4	7.5	0.46	0.42	0.40	0.34	0.34	0.31		0.24
3	7.5	0.38	0.35	0.31	0.31	0.28	0.24		
4	15	0.35	0.31	0.28	0.28	0.27	0.23		
3	15	0.27	0.24					0.24	

table 1: Friction coefficient f between cable and conduit, using paraffine oil as a lubricant, derived using formula 3. F is the load at the inlet side.

When the forces are low, not only the accuracy of the measured forces is low but also the cable stiffness plays an important role. This causes measured friction coefficients in that region that are higher than in reality, as can be seen in the left and upper part of table 1. Carrying these things in mind a friction coefficient of roughly 0.25 is found which is in agreement with the value derived from laboratory measurements.

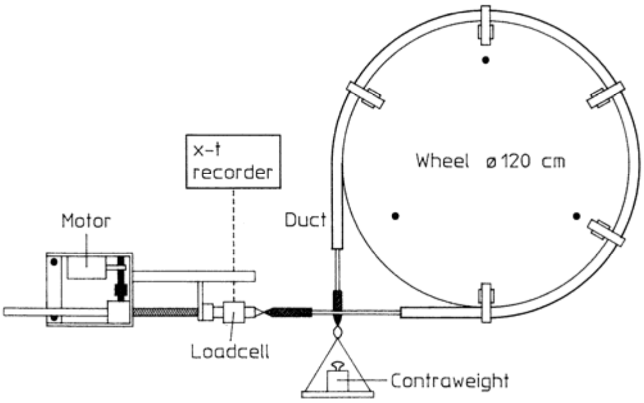

figure 5: Laboratory equipment for the determination of the friction coefficient between cable and conduit.

In figure 5 an equipment for the determination of the friction coefficient between cable and conduit is shown in which the cable is pulled through a 270 degrees section of a conduit around a 120 cm diameter wheel. The cable is pulled with a non controllable velocity of 12 cm per minute. The pulling force measured by a loadcell is monitored on a x/t-recorder. The cable is pulled with several contraweights attached at the other end. The friction coefficient is calculated using a formula which can be derived analogously to the formulas derived for vertical 90 degrees sections in [1].

$$F_2 = WR.[2f.e^{f.3/2\pi} - (1-f^2)]/(1+f^2) + F_1.e^{f.3/2\pi} \qquad (4)$$

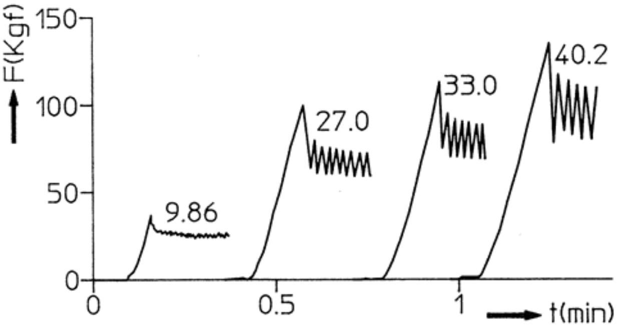

figure 6: Example of the measured force necessary to pull the cable through the conduit around the wheel as a function of time for different contraweights (represented by the numbers near the recorder traces in kgf).

In figure 6 a typical example of a recorder trace of a measurement of the friction coefficient is shown. The 'wiggles' in this recorder trace can be explained as a result of a combined effect of elasticity and inertia of the whole experimental setup [5]. The results shown in table 2 are obtained using the peak values of the recorder traces which can be considered to be the static friction coefficients. It is worth noting that not all the recorder traces look the same, for instance the water based lubricant doesn't show 'wiggles'.

contraweight (kgF)	5.0	9.86	15.0	27.0	33.0	40.2
pipe 1, dry		0.29		0.29	0.30	0.29
pipe 2, dry		0.27		0.28	0.29	0.28
pipe 1, lubricant 1	0.28	0.28		0.27	0.26	0.25
pipe 2, lubricant 1	0.27	0.23		0.26	0.27	0.23
pipe 1, lubricant 2	0.16	0.17				
pipe 1, lubricant 3	0.20	0.21				
pipe 3, lubricant 4	0.23	0.22	0.21			

table 2: Measured (static) friction coefficients between cable (standard Netherlands PTT) and several conduits lubricated with several lubricants using formula 4. Pipe 1 and 2 are standard HDPE pipes with an inner diameter of 26 mm, while pipe 3 has longitudinal ribbons. Lubricant 1 is ordinary paraffine oil, 2 is a water based lubricant, 3 is a lubricant based on triglycerine of eatable fat acid modificated by yellow amber acid and 4 is a mixture of a silicon based lubricant and microspheres.

<u>Appendix 2</u>: Measurements of the pressure decay along the conduit.

The pressure decay along the conduit is not linear because the flow cannot simply be considered incompressible in the pressure regime covering almost one order of magnitude. This pressure decay is calculated in [3]

$$p(x) = \sqrt{p_0^2 - (p_0^2 - p_1^2) \cdot \frac{x}{l}} \qquad (5)$$

with p(x) the (absolute) pressure at distance x from the air supply. The (absolute) pressures at the air supply side and at the exhaust side of the conduit with length l are p_o and p_1 respectively. In order to verify this formula measurements have been carried out using conduits with different tortuosity ranging from about 3 to 30 degrees per meter. The results in figure 7a are obtained by forcing an airflow through respectively 4, 5 and 7 pipes in cascade. These 26 mm inner diameter pipes are roughly 105 m long and measurements are carried out in the sequence of both increasing and decreasing tortuosity. The pressure is measured at the connections of the pipes.

The results shown in figure *7a* agree quite well with the calculated curve, bearing in mind the following things. After starting the compressor it took about one hour before equilibrium was reached. This can be caused by the warming-up of the compressor, the setting of a stationary temperature decay along the pipes (after some time the pipe right behind the compressor feels warm, while after 100 m underground it feels unchanged). Another cause can be the condensation and/or the evaporation of water in the expanding and cooling flow. All the mentioned effects as well as the effect of different tortuosities did not cause a significant difference between measurements and theory.

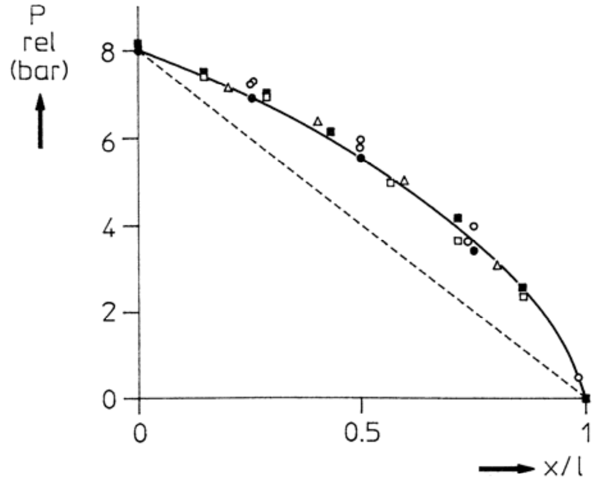

figure 7a: Pressure (relative to atmospheric pressure) p_{rel} as a function of the normalised distance x/l from the air supply. The solid curve is calculated for a (relative) pressure of 8.1 bars at the inlet side of the pipes using formula 5. The dashed line represents a linear pressure decay. The open circle, triangle and square symbols are measured at a total pipe length of 420, 525 and 735 m respectively with increasing tortuosity in the flow direction. The solid circle and square symbols have been obtained from measurements in the reversed direction at a total pipe length of 420 and 735 m respectively.

The pressure gradient dp/dx can be derived from the calculated curve in figure *7a* and is shown in figure *7b*. In the first part of the pipe this pressure gradient, which is proportional to the force of the airflow acting on the cable, is almost twice as low as the pressure gradient for the case of a linear assumed pressure decay. In the last part of the pipe the pressure gradient is almost one order of magnitude larger than in the first part. Because in most duct routes (especially in tortuous ones) the 'overforce' at the exhaust side of the conduit can not reach the shortcoming at the airsupply side of the conduit, the cable blowing can be largely improved when an extra pushing force is applied at the cable by the injection unit.

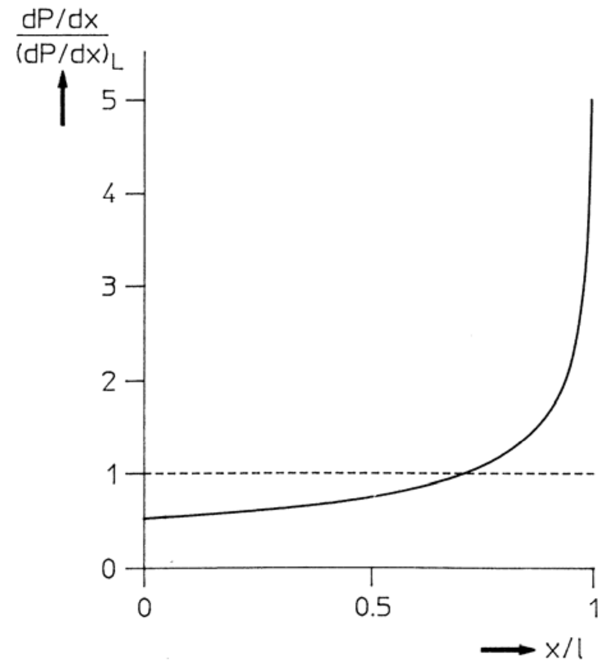

figure 7b: Quotient of the pressure gradient dp/dx, calculated using formula 5 for a (relative) pressure of 8.1 bar at the inlet side of the pipe, and the pressure gradient $(dp/dx)_1$ *for a linear assumed pressure decay as a function of the normalised distance x/1 from the air supply.*

Appendix 3: A simple experiment for measuring the cable stiffness.

Applying a bending moment to, and measuring the curvature of a cable is a way in obtaining its stiffness. A much more simple method is measuring the sag of a clamped piece of cable as a function of the weight of the mass attached at the end of it.

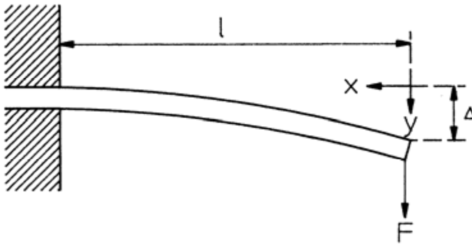

figure 8: Schematic view of the clamped piece of cable.

The sag is measured with the help of a displacement gauge. In order to eliminate the force on the piece of cable exercised by this displacement gauge (0.5-0.8 N) the situation of first electrical contact of the pin of the gauge and a piece of copperfoil, attached at the end of the cable, is measured.

The stiffness B is defined as the deriviate of the bending moment M with respect to the curvature k. For a small sag (y'<<1) this curvature is equal to y''. Using boundary conditions y(1)=y'(1)=0 this curvature can be expressed with the sag Δy=y(0) of the cable end

$$k = \frac{3\Delta y}{l^2} \cdot \frac{x}{l} \tag{6}$$

Because in the case of an elastic cable k as well as M are proportional to x the value of B can be derived from the slope of M against k at for instance x=1. When the cable is not elastic but shows a behaviour as in[4] the transition from elastic to inelastic behaviour occurs first at x=1 and translates to smaller x values when larger masses are attached to the piece of cable. This causes a smoothing of the mentioned transition. For the installation of the cable using the viscous flow of air only the elastic behaviour of the cable is of importance (worst case estimation [3]), so this smoothing causes no problems.

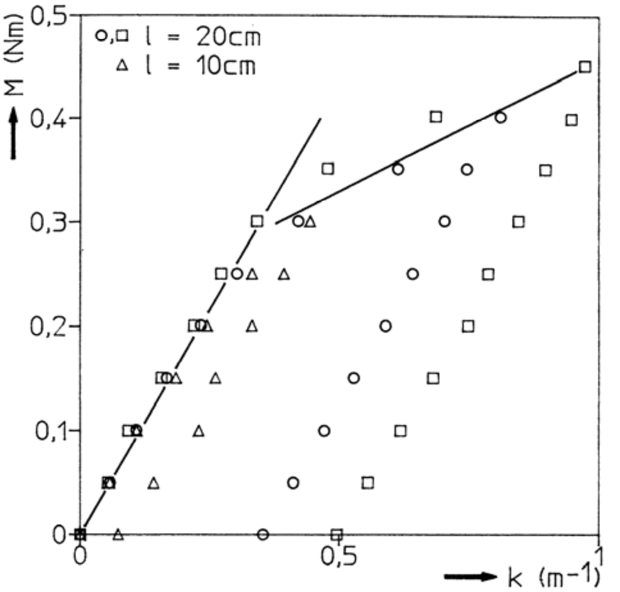

figure 9: Measured values of M against k for a standard Netherlands PTT fibre optic cable.

The measurements must be done using cable lengths and weights in such a way that y' remains much smaller than 1 and that the transition from elastic to inelastic behaviour is shown in the results. The results from the standard Netherlands PTT fibre optic cable (9.5 mm diameter, 6 fibres) are shown in figure 9. The transition from elastic to inelastic behaviour is clearly shown in measurements using a 20 cm piece of cable. For comparison measurements with a 10 cm piece of cable are shown resulting in the same slope in the elastic region. The cable stiffness B in this example can be found from figure 9 and is roughly 0.9 Nm^2 in the elastic region. This stiffness is mainly due to the aluminium waterbarrier of the cable.

Biography

Willem Griffioen was born in Oegstgeest, the Netherlands, on October 8, 1955. He received the B.S. and M.S. degrees in physics and mathematics from Leiden University, Leiden, the Netherlands, in 1978 and 1980. He worked at Leiden University from 1980 to 1984, where he investigated macroscopic quantum properties of liquid and solid $^3He/^4He$-mixtures at ultralow temperatures and in high magnetic fields. In 1984 he joined the Dr.Neher Laboratories of the Netherlands PTT, Postbus 421, 2260 AK Leidschendam, the Netherlands. His work includes research and development of fibre optic cables, installation techniques and reliability of optical fibres.