A radically new approach to the installation of optical fibre using the viscous flow of air

S A Cassidy and M H Reeve

A method of installing optical fibres in pre-installed cable bores using compressed air has been developed. The method results in very low fibre strains and avoids the need for many fibre joints. Analysis of the forces involved shows that installations of 600 m in 6 mm bores are achievable using the compressors already available on UK cabling vehicles.

1. Introduction

The small size and weight of optical fibres makes it possible to install them in cable bores using compressed air. Units consisting of several fibres in a small package are drawn into the bores by the viscous flow of the air. These units can be routed through various sizes of pre-installed empty cable without the need for fibre joints, as and when they are needed. The distributed nature of the drag force along the fibre length avoids the large end stress associated with traditional cable drawing — particularly on tortuous routes.

The empty cable can be made cheaply and installed without undue care, and the fibre unit would be a standard item to be used in any size of cable.

A fibre unit 2.5 mm in diameter containing 10 fibres and weighing 3 g/m has been installed in a cable with seven 6 mm bores along a length of 325 m using 40 psi (≈ 275 kPa) of air pressure. 50 psi (≈ 345 kPa) was sufficient to install 140 m in an internal route including 16 right-angled bends and 15 m of upward vertical length. (The maximum stress was approximately 100 gf (1 N)).

2. Installation details

The equipment needed for an installation is shown in Fig 1. The rubber wheels are driven under a constant torque just high enough to overcome the effect of the pressure drop along the air-sealing hypodermic tube, and to feed the fibre unit off the drum. Subsequently the air flowing down the cable bore carries the fibre unit along the route.

In order to predict the maximum achieveable lengths and the routes in which it is feasible to use this technique, and to investigate the possibility of optimising parameters such as sizes, materials and pressures, some analysis of the forces involved is necessary.

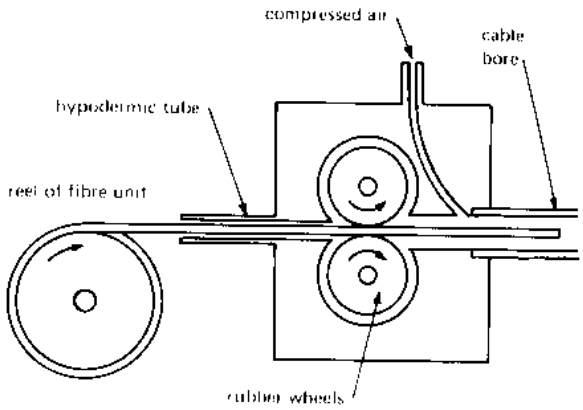


Fig 1 Installation equipment.

3. Analysis of forces

The drag force can be split into two parts: a hydrostatic or floatation force due to the simple pressure drop along the bore, and a purely viscous component due to the frictional shear force at the surface of the fibre unit.

The hydrostatic force is the result of displacing the volume of the fibre unit in a pressure gradient and is equal to the product of the volume and the gradient.

$$F = \frac{\triangle P}{\triangle L}\,\pi r_f^2\,\triangle L$$

with the symbols as defined in Fig 2. Thus the hydrostatic force per unit length is

$$\frac{\triangle P}{\triangle L}\,\pi r_f^2$$

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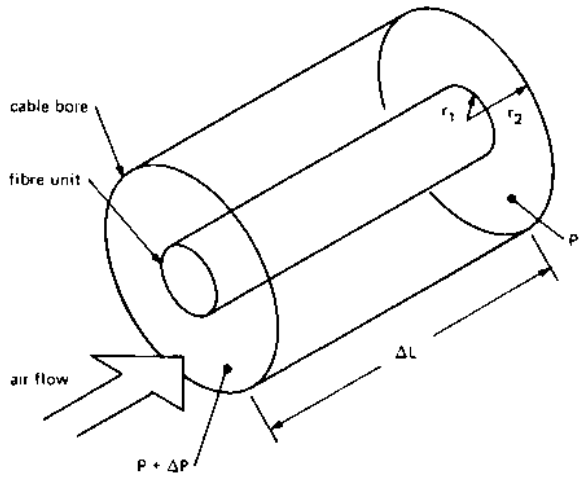


Fig 2 Notation.

The viscous force is due to the force imbalance on the annulus of gas in Fig 2. The force on the annulus at pressure $P+\Delta P$ is greater than that on the annulus at pressure P. The force difference is thus

$$\pi(r_2^2-r_1^2)\Delta P$$

and the force per unit length is

$$\frac{\Delta P}{\Delta L}\pi(r_2^2-r_1^2)$$

This force is balanced by the shear reaction around the bore and fibre unit surfaces and by the acceleration of the gas. The latter effect can easily be shown to be small for these pressures and flow rates. How this viscous shear force is distributed between the surface of the bore and the surface of the fibre unit will depend on the nature of the flow.

As can be seen from Fig 3, the flow is very turbulent in the working region, and so it seems reasonable to assume that the highly random movement of the gas

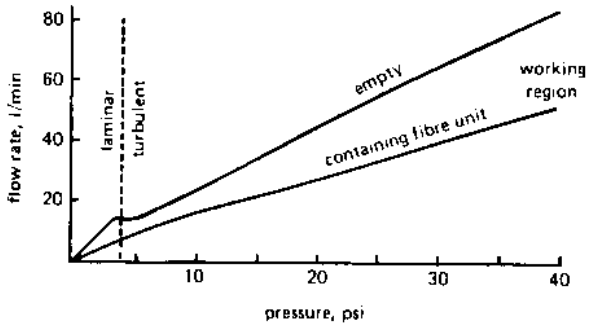


Fig 3 Flow rate versus air pressure in 170 m of 7 mm bore.

radially, spreads the shear force equally over all of the surfaces wetted by the gas. The fibre unit then has a share proportional to its share of the total surface.

$$\text{Proportion of total surface of fibre unit} = \frac{r_1}{r_1+r_2}$$

Thus the fibre unit share of the viscous part of the drag force is

$$\frac{\Delta P}{\Delta L}\pi(r_2^2-r_1^2)\frac{r_1}{r_1+r_2} = \frac{\Delta P}{\Delta L}\pi r_1(r_2-r_1)$$

Adding this to the hydrostatic component gives the total force per unit length:

$$\frac{\Delta P}{\Delta L}\pi r_1 r_2$$

4. Measurements

As an installation proceeds, and the length subject to friction and drag forces increases, the amount by which the drag force exceeds the friction will increase and be measurable as a tension at the installation end. To measure this the apparatus in Fig 4 was used.

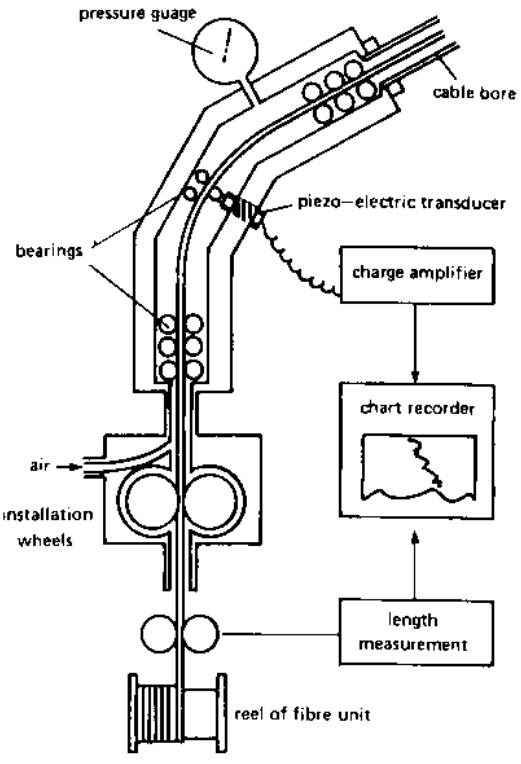


Fig 4 Tension measurement apparatus.

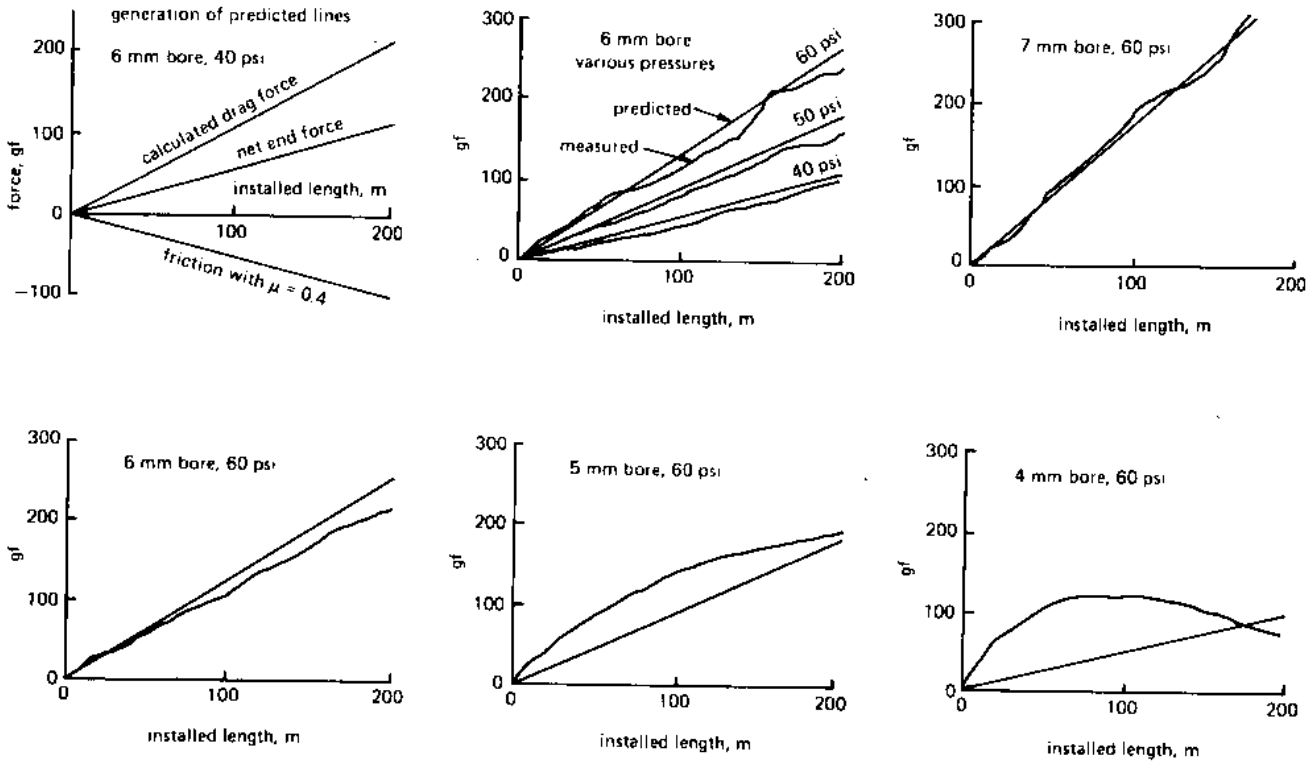


Fig 5 Some results of installation tensions with varying pressures and bore sizes.

The fibre unit runs first over a piezoelectric force transducer before continuing down the cable bore. Bearings at the entry and exit of the force measuring head prevent movement of the unit from effecting the transducer, thus allowing axial tension only to be measured. Any tension in the fibre unit is measurable as a force on the transducer.

Some results for different pressures and cable bore diameters are given below (Fig 5). The theoretical lines show the difference between the expected increase in drag and friction as the installed length increases.

It will be noted that the predictions agree well at the ends of the installations, but differ in shape appreciably for the small bore sizes, from the measured tensions. This is because a constant $\Delta P/\Delta L$ (total pressure used ÷ total bore length) is used in the calculations, i.e. a linear pressure gradient down the bore, whereas the partial filling of the bore by the fibre unit causes a larger pressure drop along the partially installed length, and thus a larger-than-expected drag force in the first stages of the installation. This effect is obviously exaggerated when the fibre unit fills a larger proportion of the bore area.

Using the now well known technique of optical phase delay [1], a fibre strain measurement was performed on an installation using one of 10 fibres in a unit 2.5 mm in diameter weighing 3 g/m. The installation was carried out using a 7 mm bore at 80 psi (≈ 551.6 kPa). The strain versus installation length is shown in Fig 6. At the end of a 200 m run, the fibre strain was 0.022%, in keeping with the strains measured mechanically.

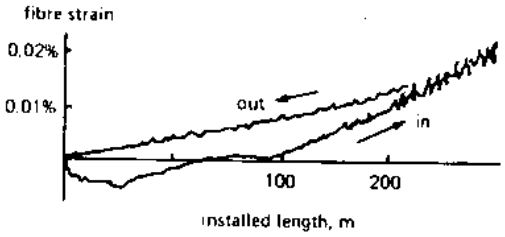


Fig 6 Fibre strain during installation

5. Conclusion

A technique has been developed for installing optical fibres using the viscous flow of air. The applications for this technique lie in difficult internal routes such as data links and links inside exchanges, difficult high capacity external routes, i.e. local wideband distribution systems, and possibly in the cheap junction network.

In these applications the installation risk and capital cost are greatly reduced. The possibility of routeing from cable to cable using sets of installation wheels running in tandem avoids the need for large numbers of fibre joints. The route capacity can also be increased in line with demand.

Our measurements and calculations show that with the compressors already available on the UK cabling vehicles, 600 m is achievable and up to 1000 m in good routes, using 6 mm bores.

Acknowledgements

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Reference

1 Kashyap R and Reeve M H: 'Single-ended fibre strain and length measurements in frequency domain', Electron Lett, 16 ,No 18, pp 689—690 (August 1980).