THE INSTITUTE OF MARINE ENGINEERS

76 Mark Lane, London EC3R 7JN Telephone: 01-481 8493 Telex: 886841

TRANSACTIONS (TM)

FIBRE OPTICS IN THE MARINE ENVIRONMENT

Dr. G.D. Pitt, M.M. Ramsay and D. Gray

read at 17.30 on Tuesday, 29 January, 1980

ISSN 0309-3948
Trans I Mar E (TM)
Vol. 92 1980 Paper 8

Fibre Optics in the Marine Environment

G.D. Pitt, PhD, M.M. Ramsay, BSc and D. Gray, C Eng, FIMarE
Standard Telecommunication Laboratories Ltd

SYNOPSIS

The paper briefly describes the development of fibre optics in their historical context, before moving on to cover the use of fibre optics for high density transmission of information with pulsed lasers or light-emitting diodes. Their advantages as a replacement for wired communications, because of their intrinsic safety in hazardous spaces, are enumerated. Also described are their uses in marine and offshore installations, including sensing elements for bilge discharge, level detection, pressure and temperature, etc.

1. INTRODUCTION

The past twenty years have seen great changes in both ship and machinery control. All ships built today possess some form of machinery control, machinery parameters being displayed at a central position. In more sophisticated ships, this leads to arrangements whereby watchkeepers can be withdrawn from the machinery spaces and a "duty" engineer is on call. On-line computers are sometimes to be found, particularly for control of refrigerating machinery.

Compared with engine room arrangements, the automation of bridge functions is not so advanced. This is due in large measure to the almost infinite variety of environmental circumstances met within everyday navigation and ship handling problems, requiring human skill and judgement in interpreting data and taking appropriate action. The emphasis to date has been mainly on the provision of instrumentation which will supply more complete and accurate information as an aid to decision making. The design of ships' bridges and the layout of equipment cannot be divorced from automation since any additional facilities will influence methods of operation and, in turn, may affect optimum layout. Conversely, an inappropriate layout may prevent full advantage being taken of the facilities provided. Bridge designs exhibit wide differences, often reflecting individual preferences and different operating methods. What is universal is the spectacular increase in the equipment fitted, compared with twenty years ago.

In some of the ships built in recent years, particularly those with extensive control systems both in the machinery and in the bridge areas, there is some evidence that electro-magnetic interference can be a problem. In all probability it is aggravated by the current style of ship construction with accommodation and machinery at the after end of the ship.

There is evidence that electro-magnetic interference is the cause of a number of computer failures. This usually stops the processor carrying out its program and the stored program itself can be contaminated. Restarting the computer does not always restore the system to a fully operational state and it is often necessary to read in the program from tape, which can be a complex operation. In at least one ship, computer failure is alleged to have been caused by high frequency radio transmissions and it was claimed by the equipment manufacturer to have been due to features peculiar to the ship itself, such as the location of radio room relative to bridge. Navigational aids with a world-wide reputation for reliability have failed to operate satisfactorily in some ships, whilst operating with complete satisfaction in others.

Type testing of equipments has occasionally been suggested as a cure but, in the authors' view, this is unlikely to provide a solution. An item of equipment may successfully pass all type tests specified, both for performance and against the marine environment; yet such a piece of equipment may fail to perform satisfactorily on board when placed in close proximity to other items of equipment.

Some information is available on cabling techniques, e.g. the use of twisted pairs, the use of screened cables and the physical separation between cables, but little, if any, quantitative information is available on the subject. Where cases of interference are experienced they are dealt with on an *ad hoc* basis. With the increasing use of electronic equipment in ships, it will be essential for electro-magnetic compatibility to be taken into account at the drawing board stage. In the absence of basic research into the subject and the absence of international agreement between manufacturers, this could present problems.

1.1 The basic fibre optic system and features

One solution which now bears serious consideration for shipboard application is the use of fibre optic cables instead of conventional copper cables. The basic requirements of a fibre optic system are:

i) a light source to convert the electrical input signals into light;
ii) the fibre optic cable;
iii) a detector to convert the light signals back into electrical signals.

There are special advantages in the use of fibre optics, particularly for systems in ships, planes and vehicles:

a) Since fibres are insulators, freedom from electromagnetic interference; no cross-talk difficulties; no problems with electromagnetic pulses such as lightning; no arcing or sparking such as can occur with short circuit or open circuiting of conventional cables.
b) Since they do not carry electrical power they can be run through hazardous or dangerous zones with impunity.
c) When suitably glanded they can be passed through bulkheads and have successfully passed the standard fire test for type A 60 bulkheads.
d) There are no problems of physical separation from other cables, since fibre optic cables can be laid alongside power cables.
e) Reduced weight and volume for comparable bandwidth or transmission requirements – this can be very important when installations are required in limited duct space.
f) Security of communications, since there is no radiation emitted.
g) Wide bandwidth, e.g. if closed circuit TV were employed.
h) Elimination of earth loops.

Shipboard applications which come readily to mind are: communications, interconnection of navigational aids, aerial feeders, machinery control and signal systems of all types.

1.2 Ruggedness and basic environmental tests

In case it should be thought that, as glass is a brittle material extra care in installation and maintenance will be required, it must be pointed out that, as with copper cables, all materials are fully tested; but, in addition, and unlike copper cables, finished fibre optic cables undergo testing for physical properties and against an environmental test specification.

Some typical values on fibre optic cables tested at STL are:

a)	tensile load to break	– 50 kg (min.) to 600 kg
b)	crushing. (number of of 1000 N applied over 7 cm. length) – no failures	– 100 (min.)
c)	impact (number of cycles 0.5 kg dropped 100 mm applied through 12.5 mm) – no failures	– 100 (min.)
d)	bend (number of cycles wound and unwound on 50 mm mandrel with 100 N load) – no failures	– 100 (min.)
e)	temperature range, normally -15°C to +60°C, but this can be extended to -55°C to +150°C depending on type of material.	

Other sections of this paper give details of fibre optic cables, their usage and also details of sensing systems, but first it is worth briefly describing the historical context and development of fibre optics.

2. THE DEVELOPMENT OF FIBRE OPTICS

The guiding of light by a dielectric medium such as glass or plastic is not a new idea. In 1870 Tyndall demonstrated to the Royal Institute that light could be guided within a jet of water, and fewer than ten years later Alexander Graham Bell studied the possibility of transmitting speech on a beam of light. Several theoretical studies on the transmission of light through dielectric materials then followed, but practical limitations appeared to be too great. It was left until the invention of the cladded glass fibre in 1954 before added impetus was gained.

The use of a cladding of slightly lower refractive index than that of the core material enlarged the permissible diameter of the fibre. The cladding could easily be made sufficiently thick to minimize losses in the surrounding air. The principle of light guidance down a clad fibre is illustrated in Fig 1.

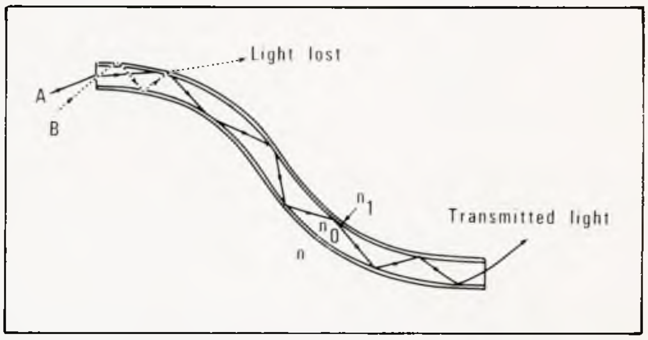

FIG. 1 Schematic diagram showing light rays being transmitted down a fibre (n = refractive indices)

Further experimental and theoretical studies of this class of fibre optic light transmission medium followed. Attenuation of light levels were usually high, due to the relatively poor quality of the materials used. It was in 1966 that Kao and Hockham, working at STL, first described the possibility of an optical communication system using a single mode optical fibre as the transmission medium. Subsequent progress in research leading to engineered optical fibre systems has been extremely rapid, to the extent that some systems involving long range transmission of data by silica are now in service.

In a basic fibre optic system the electrical signals to be transmitted are converted into light signals by a semiconductor light-emitting diode or a laser diode and transmitted through an optical fibre to be finally converted back to electrical signals by a silicon or other suitable detector. It is not often that a link can be installed complete without any joints, so it has been necessary to develop connectors and splicing techniques to facilitate installation and removal for maintenance. Those currently being manufactured have losses of about 1 to 2 dB. For permanent installations, splices can be made with much lower losses, but they are seldom necessary in links less than a few kilometres in length for communication purposes. However, for installations where shorter distance transmissions are necessary as on ships, the quality of connections need not be so high, but the ease of connecting is highly important. The discussion of splicing follows in section 2.3.

2.1 Fibre Waveguides

The preparation of highly transparent sodium borosilicate glass fibres with cladding to confine the light has advanced dramatically in the last ten years. Radio frequency induction techniques can be used to melt the glass, since at temperatures above 1300°C there is sufficient conductivity to couple the melt and the 5 MHz coils which are used. By varying the composition of glasses in two essentially concentric crucibles and also adjusting their relative temperatures, the clad glass can be drawn from a nozzle at the end of the crucibles. Great care is necessary to ensure cleanliness and to exclude the impurities in the glass (e.g. copper and iron) which might absorb the light at the critical transmission optical wavelengths. The dimensions of the glass fibre are simply adjusted by using different crucible nozzle diameters. The fibre is then pulled by direct take-up on a drum which rotates at the required speed beneath the furnace.

The above is a very simplistic description of multicomponent glass fibre preparation. The manufacture of ultra-pure high transmission silica fibre is very difficult. Simply, the core and cladding silica contains suitable dopants so that the core has a slightly higher refractive index than the cladding. The material is grown from vapour and is deposited on the inside of a silica tube: deposition occurring in a hot zone heated by an oxy-hydrogen flame. To obtain a uniform deposit the flame is traversed along the length. From a 1.8m long preform, fibre lengths up to 12 km (100μm diam.) can be obtained.

With this technique the refractive index can be varied such that discrete refractive index steps across the fibre or, graded structures can be obtained. This means that the nature of the optical propagation down the fibres can be varied to suit the type of application (see Fig 2). The design of the fibre in terms of the refractive indices of the core and cladding as well as their respective dimensions can affect the time dispersion of pulses transmitted. If the dispersion is large it becomes more difficult to transmit a high information density that is decipherable. Close control is therefore necessary to limit errors in the fibre optic refractive index profile during manufacture.

2.2 *Cabling*

If the very low attenuations which have been achieved in fibre waveguides are to be carried through into practical cables, it is essential that the stress systems introduced at each stage of cable manufacture be understood and controlled. It has become clear that the stress system built into a fibre and, particularly, the surface damage during the fibre-pulling process can be important. On-line coating of fibres with various plastics to protect their surface immediately after pulling gives very large increases in maximum load and strain. Statistical analysis of tensile tests on the best show failure at 100 N load and strains up to 8%, unprecedented levels for other structural materials. Fibres with a guaranteed 1% breaking strain over a 10 km gauge length can now be produced, with an estimated life of at least 50 years when operated at 30% of the minimum breaking strain.

For less expensive fibres for communication purposes over short distances, plastic clad silica fibres have been developed. Simple plastic fibres and bundles can also be used, although their absorption in the visible and near-infra red wavelengths are relatively high.

Thick coatings of polypropylene nylon or other high modulus plastics, which provide a composite suitable for use in a conventional cabling machine, have been achieved with virtually no increase in attenuation (see Fig 3). By laying eight such composites around a strength member, and shrouding them in a polythene sheath, cables have been made with an attenuation below 4 dB/km at 850 nm. Under these circumstances it is possible to visualize fibre optic cables centralized to a control point, gathering information from all parts of a ship, oil rig or petrochemical plant, where electrical hazards are a real problem.

2.3 *Jointing*

Joints will be required at each source and detector. In systems, most problems occur at the interfaces. Demountable couplings will be required at the transmitter, receiver and all intermediate repeaters when these are incorporated. In addition, splices may well be needed during cable manufacture and installation or to take account of accidents during service. No major problems are anticipated for the joints between the optical fibre and detector, and new systems are available from major suppliers who provide sources and detectors compatible with supplied fibre optic diameters. However, when energy is launched from an isotropic source, such as a light-emitting diode, large losses are inevitable. In short-haul systems, where such losses are not disastrous, the spare radiation can be used to provide feedback circuits and control of the light output with varying temperature. Although the source and detec-

FIG. 2 Typical range of optical fibre cables

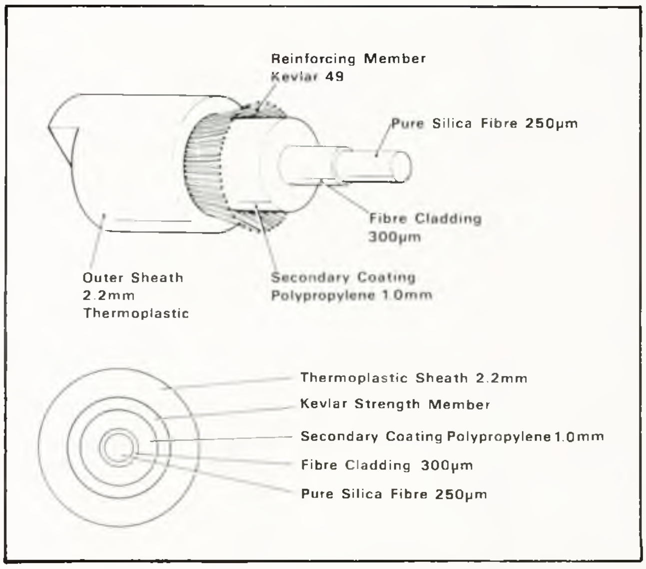

FIG. 3 Optical fibre design with the reinforcing member around the optical fibre

tor interface problems appear to have been solved with losses of approximately 1 dB, in-line splices for communications purposes must have a loss of under 0.25 dB. Fusion techniques are well-established for silica using an arc or flame. However, variations in core diameter must be below 1% and lateral tolerances or eccentricities below 3.5%, if these losses are to be met with random splicing of fibres from different manufacturing batches.

Fusion splicing has proved to be most reliable and capable of resisting high breaking strain. However, this type of jointing cannot be carried out in a hazardous space unless the ship is gas freed. Hence, a breakage during operation in such a "no-go" area could be a serious embarrassment. The solution at present for short distance installations on mobile units such as ships and aircraft, is to use couplers and connectors, which tend to have higher insertion losses near 0.5 to 1 dB, but which are quite adequate considering the relatively short distance transmissions. Alternatively, some degree of cable redundancy can be built into the system. Commercial connectors are now available, using careful alignment techniques; but it is fair to say that at present this area has not been wholly resolved.

Nevertheless, there are now several examples of shipboard installations where splicing has been carried out in safe areas, and the engineers involved were claimed to have been non-specialized.

2.4 Optical sources

Low information rate systems of modest length can be made to operate with conventional solid state light-emitting diodes of the kind now commercially available. These are most conveniently used with fibre optic bundles because of their inherent low brightness. Other laser sources with external modulation are being studied but, attention should be realistically confined to high-intensity, light-emitting diodes and semi-conductor injection lasers, both of which can be modulated directly by control of their current drive. Both have reached their most advanced state of development using gallium arsenide (GaAs) and/or gallium aluminium arsenide ($Ga_xAl_{1-x}As$) and emitting in the spectral range 800 to 900 nm; i.e. the near infra-red region of the spectrum which is not visible to the eye.

The problem with solid state devices is that the light is not necessarily confined to one direction. However, recent advances have provided packaged devices with lenses which are ideal for guiding into fibre optic bundles. Alternatively "pig-tailed" devices are on the market in which an optical fibre is incorporated into the package. Recent laser semi-conductor chip design has further improved optical confinement and launching.

The semi-conductor laser can emit higher power than the light-emitting diode (LED). Typical values are 200 mW peak power for a Ga/AlAs pulsed laser and 5 mW for a high power LED. For the lasers, however, the pulse width and repetition rate can be adjusted such that mean power levels do not exceed typically 1 mW and there is little or no safety problem.

The spectral width of the LED (approximately 300 nm) emission peak, is larger than that of the laser (2 nm) and this can lead to dispersion problems, but not sufficient to prohibit their use for relatively short-distance data transmission. At this stage the LEDs tend to be cheaper, e.g. £5 as distinct from solid state lasers which can cost between £30 and £200. However, laser costs are already falling, and will continue to fall rapidly in the coming years as more lasers are produced.

Lifetimes of LEDs are in excess of 10,000 hours within the temperature range -50 to 70°C. Lasers can now operate at temperatures up to 90°C and lifetimes in excess of 10,000 hours are now achieved. When operated pulsed and with a low duty cycle (e.g. 1%) they can now be seriously contemplated for more rugged applications. For example, the use of the solid state laser for oil content monitoring is one of the first industrial applications of a semi-conductor laser outside the communications sphere. The small size of these devices is another attractive feature, in that light sources and detectors can be mounted in standard electronic equipment practice racks. Fig. 4 shows a laser diode within a normal package – the size of the diode is approximately a 0.1mm sided cube.

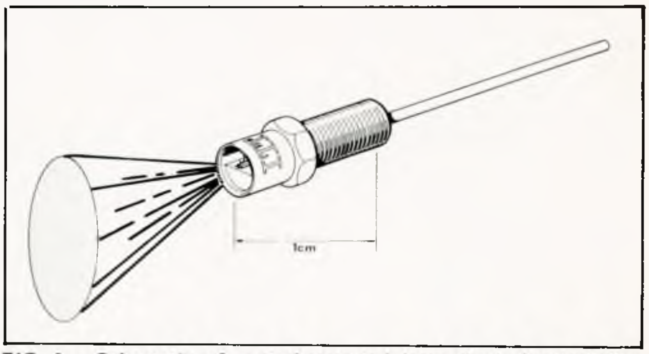

FIG. 4 **Schematic of a stud-mounted laser diode (typical dimensions of the package 1cm long and 0.4cm diam; device on the ledge 0.1mm cube with light emitted in a fan)**

3. FIBRE OPTIC SYSTEMS FOR COMMUNICATION PURPOSES

The main thrust for the development of optical fibres to date has naturally concentrated on information transmission for wideband systems in trunk telephone networks. However, the rapid expansion and improvement in technology in the past ten years has tended to broaden this interest. The high quality of the glass fibre now produced, coupled with the advent of new signal processing techniques for optical signals, has resulted in a rapid expansion of military, industrial and other civil telecommunications markets.

The high bandwidth made available using fibre optics means that transmission capacity can usually be increased and, hence, the cost per channel is reduced. As a result, hardly a week goes by without the announcement that a new fibre optic link has been successfully installed somewhere in the world. The British Post Office for example, following the successful field demonstration of a 140 $Mbits^{-1}$ system in 1977 by STL and STC in normal telephone ducts between Stevenage and Hitchin (where live traffic was carried), and their own equally successful experiments between Martlesham and Ipswich, has expressed confidence that telephone conversations by glass fibre will figure prominently in their toll network by 1990.

For marine applications, however, we are more concerned with shorter distance systems. In these areas the military have taken the lead, taking advantage of such fibre optic features as high integrity, robustness and lack of weight and volume. In the early stages, therefore, the cost of a system was not a primary consideration, although naturally it did play a part.

As described in the introduction, the highly noisy electromagnetic interference to be found on ships, aircraft and other mobile carriers of electronic equipment are tending to make this area one of the most active in terms of trial installations and tests. ITT has been active in providing fibres for several such trials and it is becoming increasingly apparent that the immunity advantages of fibre optics provide the solution in a way that is both practical and cost effective; since, for wire systems, very expensive precautions often have to be taken to eliminate interference problems.

An optical fibre, multi-terminal data system has been designed for aircraft or naval use and this can be used as an example of typical recent developments. A time division multiplexing (TDM) technique was preferred for this system, although mixtures of frequency division multiplexing (FDM) and TDM have been used on other installations.

The design parameters using LED were:

a)	number of terminals	– up to 10
b)	bit transmission rate	– 1.5 Kbit/s
c)	transmission data rate/terminal	– 100 Kbit/s
d)	optical harness	– to be flexible and to incur maximum losses of 30 dB.

Fig. 5 shows the star type of multiterminal optical system that could be used. In this optical highway each transmitter sends to all terminals simultaneously. Losses and delays can be equalized in the terminal circuitry. Similarly, it is possible to use a multiterminal ring data system. Fig. 6 shows the transmitter design and terminal unit used in the star data system. The fibres are coupled at the centre such that signals sent from any terminal can be received at the others. This type of approach can lead to timing problems, since the appointment of only one master terminal could be catastrophic if failure occurred at that point. Hence, each terminal should be capable of instituting its own timing. Methods have now been developed to ensure that this can occur.

Different types of fibre optic multiplexing systems are being developed, and several such installations are now afloat. Typically, three optical fibres may replace several coaxial and multicored cables in order to provide an optical link for, say, radar video, aerial bearing and ships' head marker. Certainly the elimination of ground loop effects and proven robustness over many operational hours means that confidence can now be placed in fibre optic multiplexing systems. The decision to install must now reduce to a straight comparison between the inherent advantages of these systems taken with the cost, and the probability that future maintenance and interference effects will be low.

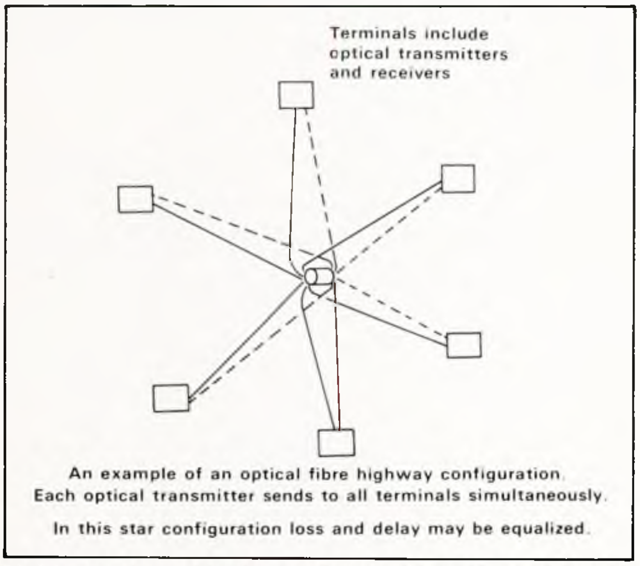

FIG. 5 A star multiterminal system for fibre optic multiplexing

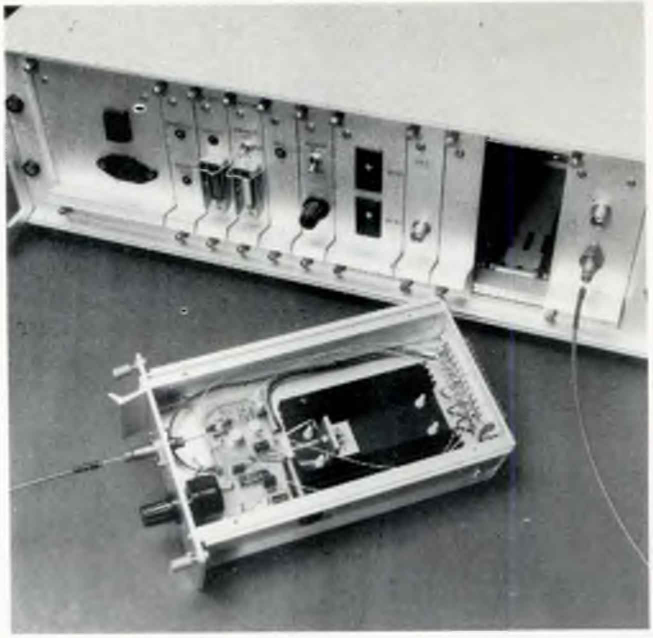

FIG. 6 A terminal used in a multiplexing system with transmitter removed to show compactness of laser drive circuitry

4. FIBRE OPTIC SENSOR SYSTEMS

Optical sensing techniques are beginning to encroach into areas previously occupied by more traditional methods. To date, the advantages of optical measurement have been largely recognized mainly for clean and controlled laboratory environments, e.g. highly accurate distance, thickness or flatness measurement. Usually these require a certain degree of stability and costly precautions against vibration problems and optical window deterioration caused by corrosion, misting or deposition of opaque materials. However, with the advent of new long-life, solid state, optical sources, and detectors, with extremely fast response it is predicted that this picture will undergo a dramatic change. This optimism results from the high compatibility of these new optical devices with the new developments in fast logic and analogue circuitry which are now coming on to the market. Since more information can be transmitted or received from a sensing element by an optical technique, new sophisticated analytical and processing devices can now be used for sensing in process control. Systems which had previously only been considered, are now feasible.

The basic sensing system can be simply described. Light from a source is guided into the fibre optic bundle or single optical fibre and hence to the sensing point. The parameter to be sensed influences the amplitude or frequency of the optical signal and the result is returned to the detector. There are two options at the sensing point:

i) The light is reflected or modulated by another sensing element so that the signal is reflected back along the return fibre.
ii) The sensor is an optical fibre itself, and this responds to some physical parameter variation. In this case the number of interfaces is minimized.

Examples are given of both these types of basic fibre optic sensing system for marine applications. A note of caution is necessary, since using the new fibre optic technology for sensing purposes runs the risk of reinventing the wheel. There is a danger of enthusiastically applying fibre optics into every conceivable area. Very often a lower technology mechanical or electrical system may well be more appropriate. Preference is given here to the description of systems which have at least been tested in the field, together with some results.

4.1 Oil in water sensors

The development of the ITT "Oilcon systems" for detecting oil in water from ballast discharges passed through two phases which can be used to illustrate both types of fibre optic sensing approaches. Fibre optics were first considered seriously for this application since the oil in water has to be measured in the pump room (hazardous space) of a tanker. Fibre optics could be used to transmit light to the sensor in the pump room through the engine room/pump room bulkhead and then retransmit the optical information back to the detection and processing electronics in the engine room.

An initial solution, which was later discarded, was to use a bared optical fibre as the sensor. Unclad silica fibre (refractive index 1.45) was immersed in the water sample extracted from the ballast discharge pipe. Oils (refractive indices typically 1.48 to 1.52, i.e. greater than that of a silica) will preferentially stick to the fibre. Light is guided down the fibre since the refractive index of water and sea water are 1.33 and 1.38 respectively, but it is then lost through the adhering oil because of the change in refractive index (Fig. 7). Sand and rust, which complicate other optical measurement techniques in this area, do not affect the attenuation of light in the fibre, as they do not preferentially attach to the fibre. Because of the very large number of total internal reflections down the small diameter fibre, the sensitivity of attenuation to oil concentration proved to be extremely high. Surprisingly, the system was found to work well with a very high sensitivity and low response time consistent with IMCO requirements. The major problems encountered were the response time on cleaning the fibres, and doubts over the whole system robustness and the provision of suitable connectors for single fibres at that time. The system could be cleaned within the required period of 20 seconds by injecting periodic bursts of detergent and air. After initial surface ageing, bared fibres were used on test for six months in flowing dirty water without any appreciable deterioration.

Eventually, it was decided to use a light scatter technique for detection of oil in water. The angle of scatter chosen for detection minimizes the spread in response for different oils, yet maximizes the response of oil relative to extraneous particulates. The cell is illustrated in Fig. 8 which shows that fibre optic bundles are passed through a bulkhead transit box in order to relay the light from the laser source to and from the cell. The intensity of light scattered from the oil droplets is proportional to the oil concentration in the water. The first certificates of type test to be issued by the UK Department of Trade (Marine Division) were granted for this system.

Monitors have now been installed for some time on tankers and in conjunction with separator systems for ballast and bilge discharges, respectively. Results from several dirty ballast discharges have now been obtained. Any problems that have evolved to date concentrate more on the sampling and mechanical details of the system rather than the use of the fibre optics, in which there has been no failure to date.

Since the fibre optic bundles have to pass through gas tight bulkheads to the pump room, fire tests on the bulkhead seals have been carried out at the Fire Insurers Research Testing Organization at Borehamwood, Herts. Certificates have been granted by the Department of Trade (Marine Division) for the bulkhead transits using fibre optic cables. To the best of our knowledge these are the first fibre optic, bulkhead seal, fire tests to have been carried out successfully and they therefore open up the whole

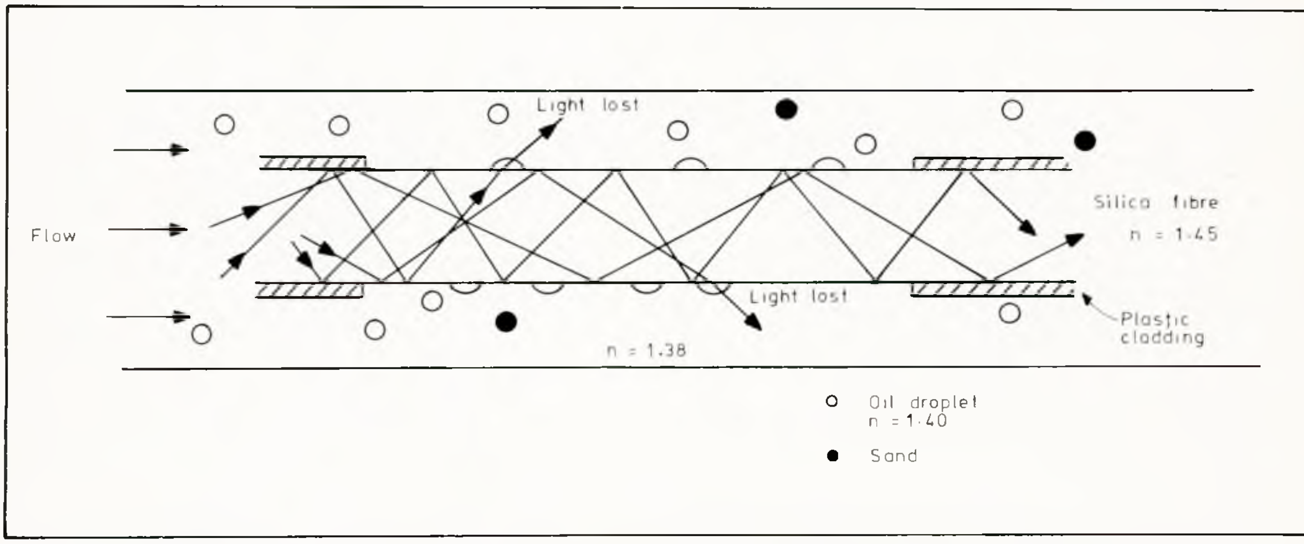

FIG. 7 A schematic of the early oil in water detection system using a bared optical fibre in the water stream

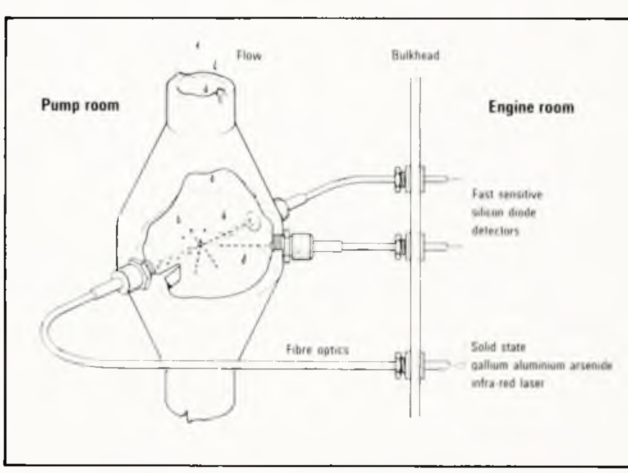

FIG. 8 Preferred oil in water detection technique where fibre optic bundles are passed through bulkhead into the hazardous space of the pump room

field for use of fibre optic sensors in flammable atmospheres.

A further extension of this work has led to trials for boiler feed applications. It has been found that the present optical system has an extremely high stability coupled with sensitivity. Boiler feed trials during the past year have successfully shown that quantities of contaminant below 1 ppm can be confidently measured. Now that boilers are being used at higher pressures than hitherto, there is some impetus for improved monitoring on the grounds of safety, energy, and conservation of water.

Oil rigs present further opportunities for oil content monitoring and other sensing requirements which are ideally suited to the use of fibre optics, and trials are now beginning.

4.2 Other sensor systems

It might be sensible in future to consider a range of fibre optic controlled sensors in the pump rooms of tankers or other hazardous marine areas on the basis that there are no electrical protection problems involved. Some examples are considered here but it should be noted that they are used principally to illustrate typical parameters that can be sensed. Their inclusion does not necessarily imply that manufactured products will be available in future, since a full technical/cost analysis on the market will always be required before production.

4.2.1 Water in oil detection

In light transparent oils (e.g. light distillate fuel oil) a subtle variation on the present Oilcon design of cell with fibre optics has been demonstrated to measure on-line down to 5 ppm of water in oil. This is the ultimate in terms of detection in a hazardous space, where the fibre optics can be laid by and through fuel tanks. Fibre optics systems are now being used, particularly in aviation, to transmit data and as sensors because they are extremely light, have a small volume, and can also be laid through and around highly flammable fuel tanks with minimal risk.

4.2.2 Flow metering

Fibre optics have been linked with turbine or vane meters to pick off the rotation of the vanes by reflection or transmission and, as a result of the pulses obtained, the flow velocity can be electronically processed at a distance away from the sensor. One further advantage of this technique is that no friction is applied to the turbine block on picking off the signal and, hence, lower flow rate measurements can be achieved than hitherto, particularly in gases. Clearly, this technique can also be used to measure revolution rates in other machinery. Optical probing can also be extended to more sophisticated flow metering applications, where sufficient information can be obtained from some transparent liquids and there need be no intrusion in the pipe.

4.2.3 Pressure and temperature sensing

Absolute pressure measurements by fibre optic techniques are not easy since it is often difficult to recognize the zero pressure value after a pressure or temperature cycle (e.g. by counting optical fringes which all look the same). It is easy, however, to postulate a number of sensing techniques which would be highly sensitive, particularly for registering changes in pressure or temperature, and several of these are now in use.

An optical fibre can be attached to a diaphragm or bimetallic strip and the movement of light transmitted or reflected back along the fibres can be used to measure either pressure or temperature. Alternatively, use can be made of differential rates of change of core and cladding refractive indexes as functions of stress or temperature.

Temperature sensing by optical fibre has long been recognized for the measurement of black body radiation from turbine blades emitted down Y-junction fibre guides. An alternative temperature detection method would be the observation or reflection caused by movement of an expanding liquid such as mercury in a similar manner to that described in 4.2.4. Clearly, however, the number of permutations in this area are endless; ultimately, cost will be the deciding factor.

4.2.4 Level sensing

The loss of light due to external index of refraction changes, can also be used for level sensing. This is a similar technique to that originally tried with the bared fibres in attempting to measure oil in water. Systems are in use in which light is sent down a Y-guide with a specially shaped end termination. Normally when the fibre end is in air a high percentage of the light is reflected back to a detector. However, once a liquid of higher refractive index covers the end termination, the light to the detector is lost and an alarm or control system can operate a valve to stop the filling of the tank (see Fig. 9). This basic approach is not claimed to be novel, although an innovative design of the end reflector is crucial to maximize the ratio of light lost/light returned. A simple LED and detector circuit can be used. Tests on this type of system have shown that it works well in the laboratory for light crude oil samples, and several similar systems have been used in the field for clean liquid applications, e.g. petrochemicals. With water and heavy thick crude oils there is eventually a problem of the fibre optic tip coating with carbonate and other deposits, so that the efficiency of the system is lost. The advantage that the fibre optic tip can fit into extremely small volumes, however, is worth consideration.

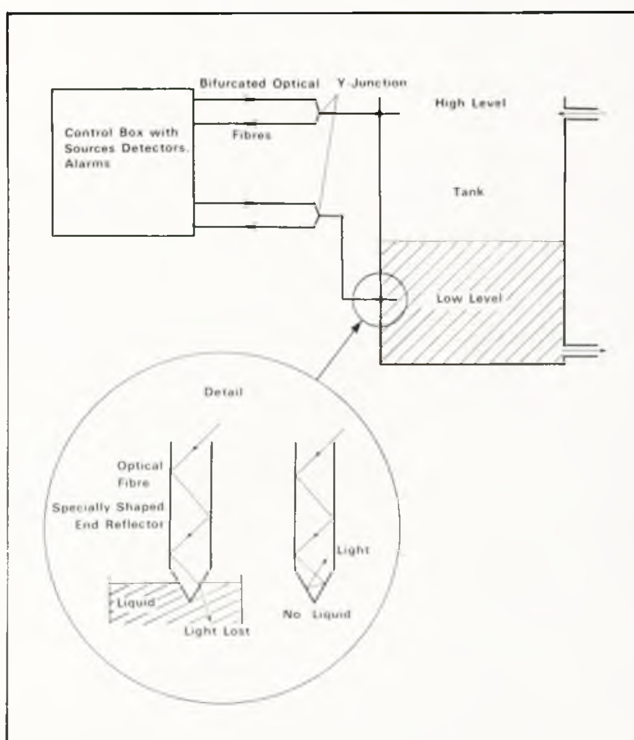

FIG. 9 Schematic representation of a fibre optic level sensing system

5. CONCLUSIONS

The transfer of relatively high technologies from the laboratory to the field is often fraught with problems. In the early stages of transition any field trials are critically viewed. For marine applications the cost and efficiency of installation and future maintenance requirements are also judged. Based on information gathered by the authors, there is now conclusive evidence that fibre optics can exist and operate satisfactorily in the marine environment. Trials have been in progress over several years with reports of no significant deterioration in performance. It is possibly in the installation and connector area that improvements can still be made. In the next few years, when robust, simple splicing techniques have been perfected, shipboard installations will multiply.

The use of fibre optics for sensing in machinery and hazardous spaces will rapidly increase through the 1980s, although discretion will be necessary to ensure that the attractions of fibre optics do not encourage unwarranted replacement of simpler mechanical methods. No doubt the traditional marine conservatism that exists will prevent any wild excesses in this direction.

Discussion

MR. K.A. BISHOP (BP Research Centre) opened the discussion with the following remarks:

1) His company had not experienced any trouble with fibre optics on the Oilcon Monitor; however, they were concerned about the lifetime of the laser source. One of their units had failed. Was 10,000 hours the best that could be achieved?
2) Concerning the rate of data transmission, was the system analogous to the electrical system, i.e. higher frequency – greater losses?
3) At BP Research Centre they were attempting to identify the contents of crude oil tanks. Would it be possible to use fibre optics and the difference in refractive index of different crude oil/fibre interface to identify the contents of different tanks?

MR. J.D. BOLDING, CEng, MIMarE (Lloyd's Register of Shipping) made the following comments:

1) Sand particles coated with oil gave false readings for oil in water content.
2) The time taken for fibre optics to be developed seemed rather long. Did that mean the viability of the product was questionable?

MR. G.E. WOODLIFF, CEng, FIMarE (GEC Electrical Projects) had been interested to hear the authors' comments regarding the application of fibre optics to vortex measurement. Vortex techniques had been used in connection with anemometers on ships.

Ship board anemometers were used to obtain wind velocity and direction and needed to be mounted in a prominent and unobscured position. Hence, it was desirable for them to need little maintenance and, additionally, being frequently mounted adjacent to radar antennae, should not be subject to r.f. interference.

The traditional anemometer utilized a rotating cup generator and a vane to give wind velocity and direction. Recently, wind velocity had been sensed using an electronic vortex detecting circuit mounted in a rotatable vane. The velocity was sensed by the vortex element and the direction by the position of the vane.

The most recent proposal had been to use two static vortex sensing vanes at right angles and to obtain wind velocity and direction mathematically by the vector measurements from the two sensors.

The use of fibre optics for such an application would be most usefu' since, presumably, it would enable the electronics to be mounted remotely from the sensing elements in an accessible position, not subject to r.f. interference from the radar scanner. He would like to hear the authors' comments on the technical aspects of such a proposal.

Could the authors also comment on whether it was possible to provide the equivalent of slip rings in fibre optic technology, i.e. was it possible to transmit fibre optic signals between fixed and moving surfaces without significant attenuation at the interface?

MR. C.J. LEWIS (National Maritime Institute) asked for further information concerning:

1) joining fibre optics in the field;
2) attenuation due to bending;
3) interfacing with conventional (electrical) transducers.

MR. J.D. McIVER (Cammell Laird Shipbuilders Ltd) said that Mr Gray had indicated in his opening address that the problems with electronic cabling in ships could be related to lack of an installation guide. It was to be hoped that a practical guide would be provided for the installation of fibre optics from the outset.

In response to an earlier question, it had been inferred that optic fibres would be selected for each application, while the Industry would anticipate having a range of standard fibre optic cables to select from, and not be involved in a special design, etc. Was it possible to indicate any standards or standard range that had been proposed?

Was it also possible to indicate for a multi-core fibre optic cable the bending radius and diameter of that cable?

Had a fibre optic cable been installed in a compression gland, and were there any torque requirements for tightening the gland in order to prevent damage to the cable? On a similar theme, had that type of cable been subjected to a pressure test, i.e. could it be used outside the pressure hull of a submarine?

Finally, while appreciating how optic fibres could remove or reduce the EMC problems, there was the danger that the problem would merely be transferred to the optic/electronic interface, unless stringent precautions were taken at the control stations or marshalling points. What was the state of the Art in that field?

MR. R.G. BODDIE, CEng, FIMarE wrote that the authors had assumed that all readers of the paper would possess a basic knowledge of light and fibre optics. A number of statements had been made without a full explanation and, for the benefit of the non-expert, could the authors provide further information?

He was particularly interested in the concept of light and power; why was glass free from electromagnetic interference; and, what happened to the light which was lost from a fibre on a bend (see Fig.1). The conversion of an electrical signal into light was an interesting phenomenon, bearing in mind that one author had said that it was possible to overload and damage a fibre with light. What was the process for such damage?

Finally, could the authors give an order of the cost of fibre optics compared with conventional units?

Author's Reply

To Mr. Bishop the authors replied that fibre optics could be used to measure differences in refractive index of crude oil using the attenuation of light effect down fibres. However, they would not recommend that as a practical instrument for operation in the field. There were large variations in oil type and viscosities, such that cleaning the fibres after dipping into the crude oil would be extremely difficult for consistent and absolute measurements to be possible. Nevertheless, the use of a fibre optic core acting as a spectrophotometric tool in the laboratory was a distinct possibility, where clean liquids were to be tested. The large number of reflections in a small diameter fibre meant that the surface sensitivity to total internal reflections had to be extremely high.

Ten thousand hours operation was certainly not the best that could be achieved with a semi-conductor laser source. Early examples certainly had spectacularly short lifetimes, but thorough investigation of the failure mechanisms and appropriate remedial action had led to semi-conductor laser sources which had operated for five times as long, and over 100,000 hours could be confidently predicted.

It was not certain whether Mr. Bishop had suffered a failure in the drive circuitry or the laser. Without further details of the problem and mode of operation it was difficult to make an assessment of the specific point. It should be noted, however, that for discontinuous ballast operation, the likely operating time was only approximately 400 to 500 hours/year.

At the information rates normally considered in the marine environment, there was no analogy between a fibre optic system and an electrical system. It was true there was a dispersion penalty associated with high frequency transmission, but not extra loss, and the penalty was not as severe as in the electrical case until extremely high information rates were reached.

In answer to Mr. Bolding's queries, sand particles tended to be coated with oil less than rust. Rust particles were oleophilic and oil could seep within a loosely bound group of rust particles. Therefore, if any optical technique was used, rust and sand particles must shield some of the oil and that would be reflected in the output. That was the same whether the optical technique used fluorescence or absorption techniques. The objective was to minimize the effect of rust and sand to an acceptable level. Using light scatter techniques, that could be done relatively simply for single particle measurement with lasers and polarization effects. However, for the multiple reflection case the problem was very complex. They had carried out exhaustive testing, together with theoretical computer modelling, such that some understanding had been gained. The major perturbing factor tended to be a high density of very small particulates (i.e. less than 1 μm diameter). With 100 ppm of 1 μm particles in suspension any liquid became practically opaque and any measurement must be extremely difficult. However, the situation became much clearer as the particle size increased. To date, based on field results correlated with sampling procedures, the effect of extraneous particles had not posed a major problem and had remained within the IMCO specified tolerance limits.

To illustrate the effect of attachment of oil to rust, tests had recently been carried out on very pure condensate water where oil concentration levels were less than 1 ppm. It was found that variations in the iron concentration closely followed any oil concentration. Therefore, even at very low concentrations, it appeared that the oil would attach to any rust that was available. In ballast or bilge tanks, the effect would be to increase the particle size slightly and reduce scattered light output (large particles tended to forward scatter less than small particles), but the effective particle density was increased with a subsequent increase in scattered intensity. The two opposing effects had a partial cancelling effect. That helped the overall measurement.

The use of fibre optics was put forward at STL in 1966. The development since then had concentrated on the material properties of the high purity glass and the solid state lasers. Any development concerned with extremely high purity semi-conductor or composite materials was extremely difficult. It was a measure of the speed at which things were moving in the fibre optic area that the technology for source, transmission medium and detectors had all been accomplished in approximately ten years, and operating systems were now available and working in robust environments. That time scale could be compared with the 30 years required to develop the transistor, which consisted of only one element – silicon.

It was concluded that the viability of the product was not questionable. Nevertheless, the very fact that the question had been asked indicated that there would be some resistance to full and immediate acceptance of the technology. The only way to convince users of the advantages was to run systems for periods in the field. The authors felt that sufficient information was now available from systems in use, such that potential users could ask for, and receive, sufficient "on site" information upon which to base satisfactory decisions.

To Mr. Woodliff they replied that they had used fibre optic sensors to measure vortices in both gases and liquids. Tests had proved highly satisfactory, operating down to extremely low flow rates with good accuracy. The prospect of using those techniques to obtain wind velocity and direction was definitely feasible, and development of such systems would be an exciting prospect. Isolation of interference from the radar scanner would certainly be a significant improvement over electrical measurement techniques.

It was perfectly feasible to launch into or receive light from a fibre optic which was rotated around its own axis. That technique was used extensively in the manufacture and cabling of optical fibres to monitor the effects of the processes used. It was rather more difficult to launch into a fibre rotated around other axes, but some ideas were currently being explored, with definite objectives.

Mr. Lewis was assured that techniques had been developed for splicing fibre optics by fusion, using either a miniature oxy-hydrogen flame or a micro-arc. Both those techniques had been used successfully in the field. Indeed, single mode fibres had been spliced on board a cable ship with the engines running, with a loss penalty of about 0.25 dB.

Outside the core of an optical fibre waveguide there was evanescent energy associated with the bound waves guided by the core. That energy fell off exponentially with distance from the core, and the slope of the exponential was governed by the characteristics of the guide. That energy fell to zero at infinity and was in the form of a plane wave travelling in the surrounding media. If there was any curvature, it followed that at some distance from the guide the phase velocity of the plane wave would exceed the velocity of light in that medium and the wave would radiate. That meant there was always some loss unless the waveguide was absolutely straight. However, the energy fall-off was a steep exponential and, therefore, the amount of energy lost could be quite negligible or extremely high, depending on the waveguide and the curvature. A typical waveguide could have very low losses down to a radius of curvature of 5 mm, and rapidly mounting losses below that radius.

For sensing applications, however, it was possible to make the fibres with core and cladding refractive indices, such that any stress or strain effects could cause attenuation. It was clear, however, that such designs would not be contemplated for transmission fibre.

Certainly it was possible to interface fibre optics with conventional electrical transducers, and it could be argued that it would be the least risky method of introducing fibre optic systems. An electrical output signal could be transferred to an optical signal for transmission after amplification. Optical techniques could pick up mechanical movement accurately, and also digital information, e.g. rotating vane of a turbine meter.

Mr. McIver should see a well-established range of standard fibre optic cables within a few years. At present, the British Standards Institute, the International Electrotechnical Commission, the CCITT and the MoD were all considering standards for fibre-optic cables and all those bodies were interchanging information. Certain fibre optic waveguide designs were already emerging from these deliberations, and others would follow.

Normal cable practice indicated a minimum recommended ratio of curvature about ten times the cable diameter. Multi-core fibre-optic cables were just like any other cable in that respect.

Fibre optics had been installed in pressure glands in laboratory experiments where the torque requirement related to the experimental detail. The effect of hydrostatic pressure could be seen from Fig. D1 to be quite negligible and the cables could certainly be used outside the pressure hull of a submarine.

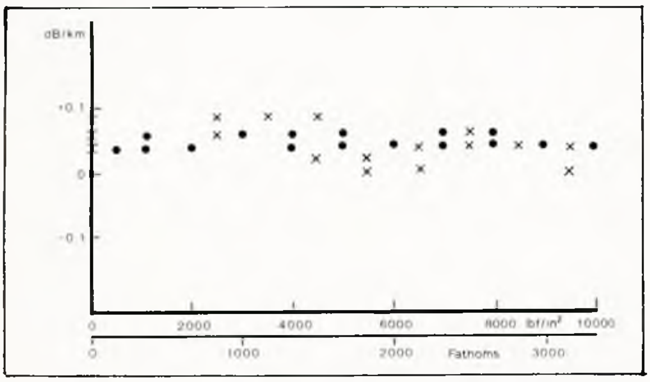

FIG D1 **Incremental loss on a fibre optic cable bulkhead seal as a function of hydrostatic pressure and depth below sea level**

It was very much easier to deal with EMC on a localized basis where the danger was recognized rather than on a random basis down lengths of cable. However, Mr. McIver had been quite right to draw attention to the dangers inherent in control stations and marshalling points. Care would have to be taken at those points.

To answer Mr. Boddie's questions fully would mean that they would have to revert to the basics of light transmission and compare it with electrical current. It was, perhaps, difficult to equate the transmission of optical power down fibres with safety in hazardous spaces. It was probably best to start by stating that glass was effectively an insulator and any electrical eddy currents which could be transmitted to a fibre were therefore negligible and, hence, no interference effects were found. Power in the form of electromagnetic radiation could be transmitted down an optical fibre. Thus, very high power laser light could be a problem if the light escaped due to breakage and subsequent heating of explosive gas or liquid. Extremely high light power levels could damage fibres. However, for communications and sensing purposes the powers used were many orders of magnitude below that level and were generally in the region of microwatts or below. Therefore, the hazard due to the escaping, unfocussed light was less than the effects due to normal daylight. Hence, there was no danger of arcing or sparking when cables were cut or damaged.

The effect of bending of optical fibres had been explained in answer to previous questions, but again the loss of light on bending involved power levels many orders of magnitude below anything which would provide a hazard. The reason that those very low power levels could be used to transmit information was due largely to the development of the extremely pure high transmission glass.

The costs of fibre optical systems were reducing and ease of installation had improved as a result of the technical development. It was not possible to give specific cost comparisons, since the applications were so many and varied. Nevertheless, if the application was thought to be suitable for fibre optics, cost comparisons should then be carried out. Recent reviewing of several projects had shown that comparability was close for several areas. Taken with the technical advantages of fibre optics the solution was becoming attractive on an all-round basis.

Published for THE INSTITUTE OF MARINE ENGINEERS by Marine Management (Holdings) Ltd., (England Reg. No. 1100685) both of 76 Mark Lane, London EC3R 7JN. Printed by Crown Printers (Bedford) Ltd., Bedford (England Reg. No. 910307).