



**ÉCOLE POLYTECHNIQUE FÉDÉRALE
DE LAUSANNE**

**LABORATOIRE
D'ÉLECTRONIQUE GÉNÉRALE
16, CHEMIN DE BELLERIVE
CH - 1007 LAUSANNE / SUISSE**

**INSTITUT
DE MICROTECHNIQUE
114, ROUTE CANTONALE
CH - 1025 ST-SULPICE**

**JOURNÉES D'ÉLECTRONIQUE
ET DE MICROTECHNIQUE 1980**

**"LES LIMITES DE
LA MINIATURISATION"**

**"LIMITS TO
MINIATURIZATION"**

ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
SWISS FEDERAL INSTITUTE OF TECHNOLOGY – LAUSANNE

COMPTES RENDUS DES
PROCEEDINGS OF THE

JOURNEES D'ELECTRONIQUE ET DE MICROTECHNIQUE 1980

sur le thème / on the subject

LES LIMITES DE LA MINIATURISATION
LIMITS TO MINIATURIZATION

Manifestation organisée les 7, 8 et 9 octobre 1980 à l'Aula de l'EPFL

* * *

Les Journées d'électronique et de microtechnique sont organisées avec l'appui de :
The Journées d'électronique et de microtechnique are supported by :

- **Association suisse des électriciens (ASE)**
- **Association suisse de microtechnique (ASMT)**
- **Ecole polytechnique fédérale de Lausanne (EPFL)**
- **Institute of Electrical and Electronics Engineers (IEEE), Region 8 et Section suisse**

ON THE LIMITS TO MINIATURIZATION OF FIBRE-OPTIC TRANSDUCERS FOR
PRECISE AND UNDESTURBING MEASUREMENTS IN ELECTROMAGNETICAL AND
ACOUSTICAL FIELDS

R.S.ROMANIUK

TECHNICAL UNIVERSITY OF WARSAW

1. Introduction

In many questions of contemporary technique there exists a problem of measuring of various physical quantities or a problem of transforming one type of signal into another. Let us consider an automatic system with reference to a process under control and regulation. Such a system can be generally presented as a feedback between a transducer cooperating with measuring part of a device and executing part. In order to fulfill its task the transducer has to, in direct or indirect way, participate in changes going on in the process. There exist two main aspects of this participation. Firstly, the converter can not act upon the process in this way that it changes the parameters of it or in great degree changes the entropy. Secondly, if there is controlled a complex process /ie. simultaneous control of many variables like: temperature, pressure, volume, fields - in case of measuring certain parameters of an object under the influence of external radiations eg. X-rays, optical, microwave acoustical, etc./, the converter is exposed to other actions which can influence upon its work.

The features of ideal converters seem to show fibre-optic transducers. They can be performed in very small dimensions in comparison with other devices. They can be made as immune against other drastical expositional actions. Their work characteristics can be shaped in very broad range, adjusting them to the needs of an arbitrary controlled and steered process.

A subject of this paper are fibre-optic converters for measuring of various quantities like: mechanical /shift, force, pressure, deformation, density change, vibrations, flows/; electrical /field, current/; magnetical /field, polarisation/; ther-

mal, optical, chemical, radiational, etc. Utilized by this optical phenomena are: forced birefringence, piezooptic effect, piezoabsorption, mode coupling, triboluminescention, electrooptic and magneto optic effects, Kerr, Pöckels and Faraday effects. The problem was presented in two parts: theoretical and practical. Mathematical models of interactions between measured quantity and optical power flow were outlined. Main attention was focused on: how to utilize the acoustic sensitivity of optical fibres for waveguide detection of sound by means of specialized micro-sensors. It is well known that an acoustic wave acting on an optical fibre will give a periodic perturbation to fibre's properties. The acoustical wave can cause a change in the phase of propagated electromagnetical field or can induce controlled mode coupling between modes of certain propagation constants, both these phenomena depending on the wavelength and intensity of the acoustical field and the frequency of optical wave.

In the first part of work, theoretical possibilities of filamentary transducers were counted as well as their ranges of dynamics. Stage of complexity, dimensions, theoretical possibility of miniaturization, reliability, sensitivity, measuring precision and costs of performing were compared between fibre-optic transducers and classical systems. Broadly treated main problem of the work: the dependence of basical parameters of transducers on the stage of miniaturization. It was shown, that fibre-optics technology gives the possibility, in certain fields, to construct very precise and extremely small converters. Especially it is advantageous by performing of measurements in inaccessible places.

Second part of work concerns with practical problems. Real solutions of lightguide micro-converters were broadly discussed. Their construction, properties and possibilities of applications, including quite new ones, were shown. A few limits of miniaturization imposed by performance of the transducer were presented. Technical problems connected with vibrations were emphasized. There were described specialized fibre optical and opto-acoustical micro-transducers for: opto-acoustical investigations of great masses of concrete, investigations of rotations of parts of machines, opto-acoustical investigations of vibra-

tions of biological objects, sensing of earth vibrations, dynamic pressure control, etc.

2. Miniaturization, immunity, precision and other system problems

An important problem, mainly of industrial, also biomedical metrology, are simultaneous measurements of various quantities in inaccessible or hard-accessible places. Let us consider for instance the possibility of recording of acoustical holograms of exceptionally great depth of focus. A medium, in which is propagated or on which is incident an acoustical wave of known parameters, changes these wave parameters and such changed acoustical wave is detected in the medium by an optical fibre detector. From the character of changes, the acoustical wave and next optical wave are subject of, can be inferred the character of investigated medium. The acoustical wave and the fibre-optic micro-transducer can reach the places that are inaccessible to classical metrology technique. Various criterions of inaccessibility of measured medium need there be considered. This problem appears most often by performing of measurements for example: in chemical industry in hostile environments /then the inaccessibility of measured area is connected with its hostility/, in biomedicine - measurements in vivo inside a living tissue /there the inaccessibility and problems of miniaturization are connected with the assumption that the investigated tissue can not be damaged to such an extent as to change environmental conditions/.

An important problem of the transducer's construction is the dependence of its basical parameters on the stage of miniaturization. The limits of miniaturization imposed by performance of the transducer should be presented. Questions of miniaturization are worth of considering because micro-transducer is to reach certain kinds of inaccessible places. It can be shown that fibre-optic technology gives the possibility to construct very precise and indeed small optical devices. The mentioned advantages, in certain domains of applications, render this type of transducers to be competitive against used nowadays pure electronic systems. These domains are:

- a. measuring and operational systems of high quality, high precision, in very low degree changing the entropy of a process, not damaging the environment, pattern or laboratory systems
- b. industry measurement systems and systems applied in military technique working in hard environmental conditions, compact, portable systems, broad and quick field use, not expensive
- c. measurement and operational systems designed for work in hard-accessible places.

High precision, hard environmental conditions, special safety requirements or appointment for work in inaccessible places impose on measurement systems additional demands, more than ones difficult to fulfill by classical devices. It seems that switching to optical measurement signal and utilizing elastical, silicone fibres as a channel for measurement information signals can in great degree facilitate problems appearing in the course of devising and performing of measurement and operational systems for industry as well as biomedical applications. This is because an optical feedback gives the possibility of building an unilateral twoport.

The problem of high level of outside perturbations can be met in case of application of measurement systems in energetics, heavy industry, chemical industry and military technique. As the most frequently appearing perturbation factors can be mentioned: high levels of electrical field intensity in test short-circuit high-voltage systems in power plants, transformers' stations, microwave radar stations; strong perturbations due to extremally hard work conditions of industry control units in mines, metallurgical engineering /humidity, vibrations, dustiness, elevated temperatures/; in chemical industry plants /high fire risk, highly destructive and caustic environment/.

In biomedicine this problem of high level of outside perturbations turned out to be important in case of the application of measurement and operational fibre-optic systems together with the X-ray technique. Silicone fibres are also sensitive to the X-rays. Generally can be said, that the X-rays, apart from short-term and frequently reciprocal effects, cause slow devitrification of vitreous materials.

The problem of measurements in inaccessible places can be en-

countered most often in: engineering industry /measurement of movements and vibrations of internal parts of working machines/; civil engineering /investigations of vibrations, strength, distribution of stress in great masses of concrete in dams for big storage reservoirs, in big foundations, etc./; chemical industry /measurements of some properties of media in destructive environment/; geology /seismic and hydrophonic measurements/. The problem of measurements, observations and treatments in inaccessible places can be met very often in biomedicine. This refers to the diagnostic or therapy actions carried out outside the caves of an organismus, or in very small caves, that are difficult by means of ordinary endoscopy techniques like: pan-endoscopy, laryngoscopy, laparoscopy. Various places of applications need various treatments, thus the probe, to be universal, should contain devices that are universal and of very small dimensions. It is apparent, that the problem of inaccessibility is closely associated with the stage of miniaturization.

One of the most important parameters, which can decide of next development of endofiberoscopy, is available optical acuity of systems with fibre imageguides. Connected with this optical acuity, the quality of an image depends on: the diameter of a single fibre, the way of launching of the image to the bundle, the way of illuminating of the observed object. Each broken fibre in the guide gives clear dark spot in the image. In order to prevent the serious deterioration of the picture by brokening of individual fibres, the image of the single point /especially color information of this point/ can be transported through a few neighbouring fibres in this way, that this fibres are face-connected by a small prism. Serious improvement of optical acuity can be reached by means of proper scanning illumination of the object. The fibres'bundle of the imageguide contains certain number of illuminating fibres suitably placed in the input face of the device and suitably excited. The main facility of such imageguides is that the image carried by the fibre-optic bundle is already quantized, and can be easily introduced into the computer and next digitally processed. Quite another method of improvement of the optical acuity consists in utilizing a compensating hologram. This additional hologram, through which

the image is observed, compensates the phase distribution introduced by optical fibres. This hologram, however, can be utilized only with this imageguide for which it was recorded. Utilizing also of certain nonlinear effects can lead to a profound improvement of optical acuity. The mirror of Mendelstam-Brillouin applied together with two imageguides of nearly the same properties gives images of exceptional quality.

Let us consider certain problems combined with the miniaturization of imageguides. In case of rigid devices, the considerable dependence of observable field on the waveguide dimensions can be taken as a rule. In case the imageguide is not ended with a lens, it carries the image of an object directly adjacent to its endface. The advantage of this device is great possibility of miniaturization. The drawback, however, is the limitation of observable field to the core of the fibre. The extension of observable field can be obtained by using of suitable lens performed on the endface of the fibre. This way does not increase, in considerable degree, the dimensions of the probe.

The role of a single fibre, in a flexible imageguide consisting of coherent bundle, is transferring of the point information. Thus, the limit imposed on miniaturization is not stated by the dimension of the single fibre, but by the required field of observation. From one side, the larger is the numerical aperture of a fibre, the larger also is the observable field. From another side, the larger is the NA, the larger are the peripheral distortions of the image.

The maximum stage of miniaturization can be obtained in fibre-optic transducers consisting of a sole lightguide. It is, however, to remember, that the whole dimensions of the transducer are created also by the package of a device. These last dimensions depend on the kind of application. On the average, much greater dimensions have the transducers, which possess other devices working together with the fibre like: transducers with additional medium or with noncontinuous luminous flux.

3. Fibre - optic transducers

In a fibre-optic transducer the measurement device is a filamentary lightguide consisting of two layers of a dielectric made of glass or plastics: core and cladding of refractive indi-

ces $n_1 > n_2$. In geometrical optics approximation, the light beam is propagated by successive reflections on the surface between core and cladding. Light beams can be propagated at various discrete angles /giving rise to guided modes/, inside an acceptance cone described by numerical aperture of a fibre $NA = \sqrt{n_1^2 - n_2^2} = \sin \theta_m$, where θ_m - maximum angle at which a ray can be accepted by a waveguide. Basic value describing a mode is modal constant of propagation β , connected directly with modal group velocity $v_g = d\omega/d\beta$. An optical wave propagated in a fibre is subject to changes in: phase, amplitude, state of polarization, space and time frequencies, due to interactions between measured medium and a guide. In case of a guide without a cladding, this interaction consists in a power outflow from perturbed fibre, where this perturbation stems from refractive-index changes of the cladding, formed by a surrounding medium. In other cases, it is interaction consisting in: bending, twisting, stressing of the fibre or suitable membrane by a measured quantity. In this way, the measured quantities /for instance in case of fluid's flows: intensity, velocity and perturbations/ are subject to transformation to suitable optical quantities.

Taking for the criterion the construction of transducers they can be divided into two essential types: integrating /line/ and differential /point/. Inside the frames of these two groups there can be distinguished flow /continuous/ and reflecting devices. In a line transducer the light is subject to modulation along the whole length of the measuring fibre. The signal intensity or its phase is a line integral performed over interaction length with the physical variable. The most sensitive method with the line transducers is the interferometric one. For single mode fibres a Michelson or Mach-Zender geometry can be employed, in which the fibre path interferes against a reference path. For multimode fibres the phase interference occurs between different modes within the fibre.

Taking for the criterion, from the other side, the changed parameter of the optical wave propagated in the guide, the fibre-optic transducers can be divided as follows: polarization, frequency converting amplitude and phase. Below, there was performed a short description of physical phenomena that can be used

by measurements.

3.1. Frequency transducers

Fibre optic technology uses often noncoherent optical sources /electroluminescent diodes/, because of their considerable lower cost and greater facility in splicing with a fibre in comparison with semiconductor lasers. In order to reach a great factor of the optical power acceptance by the fibre, guides capable of supporting of a great number of modes are used. In the actual waveguide with nonidealities there exists a phenomenon of mode coupling. The nonidealities can be natural or induced: material losses, bending of fibre axis, material nonhomogeneities, perturbations of core-cladding reflecting surface. In case, a dielectric material is lossy, modal constant of propagation is a complex quantity. For small losses, however, it can be assumed that the losses of individual modes of a weakly propagating fibre $/n_1 \approx n_2/$ are equal to the losses of a plain wave in an unlimited medium, on condition that the losses of core and cladding are the same. In other cases each mode shows eigenlosses and apart from mode coupling there exists also mode filtering. This effect can be employed for building fibre transducers without a cladding. Great influence on the optical wave propagated in a converter have outside actions deforming the core-cladding boundary. It is well known, that for simple sinusoidal distortion of mentioned boundary, the waveguide modes are coupled together, if mechanical frequency Θ of distortion function is connected with modal constants of propagation as follows $\Theta = b_i - b_j$. Waveguide as well as radiation modes can be coupled together. The power flow into a waveguide mode changes the shape of an impulse, while the flow into a radiation mode adds itself to the whole losses and does not change the shape of an impulse. Quite different mode of work of the fibre transducer can be observed when the multimode guide is excited by the impulse in such a way that the whole power is contained in one mode or in certain chosen modes. As a result of coupling, the power will be divided between various modes. In case of a fibre that can support a great number of modes and assuming that strongest coupling occurs between neighbouring modes, this process resembles the diffusion effect. In case of weak coupling /modal power

changes only small on the way of wavelength/ there are fulfilled Marcuse's equations [1], which establish, under additional assumptions, sufficient description of the transducer's properties. Taking the initial conditions as a set of simultaneous delta impulses, the answer depends strongly on the mode coupling and will also be a set of broadened but separated impulses, in case of a sufficiently weak coupling and a sufficiently long guide, or can have a disturbed crest, in case of a stronger coupling. The width of the output impulse is proportional to the fibre's length L , in case of sufficiently weak coupling and conversely, at stronger coupling the width is approximately proportional to the square root of L .

In a little different way, the parametric mode coupling can be obtained by modulation of a fibre axis' bending radius by means of the acoustical wave. This effect is rather curious, because has the characteristic in a shape of descending wave-like curve. After total cut-off of a mode, there appears a little, short-lasting increase of the transmission due probably to decrease of coupling coefficients for high-order modes.

Another type of frequency transducers are these with Doppler effects. Because of their well known theory they will not be described right here.

3.2. Polarization transducers

The waveguide modes are linearly polarized in the ideal multi-mode fibre. The polarization changes in certain and approximately known way in the actual fibre. A change in the polarization can be attributed to core deformations /mainly elliptical/, and the loss of linear polarization can be described as the coupling of orthogonally polarized modes. Isotropic core deformations can cause the coupling between orthogonally polarized modes only through longitudinal components of the fields. The influence of E_z components is usually omitted, because it is considerably smaller than the insult of transversal components. In case of the lack of coupling of transversal components, coupling of E_z has to be taken into account. Thus, only elliptical deformations of the core cause orthogonally polarized modes to couple. Even for extremely weak ellipticity and very small E_z components, the whole exchange of the modal power /90° change

of polarization/ occurs in the guide on the distance of a mere few centimeters. This distance decreases for higher order modes. Due to random perturbations of the core, the value and direction of the ellipticity slowly changes, what results in random changes in polarization. Additionally, in the elliptical guide, two associated modes orthogonally polarized /odd and even/ have a little different values of modal constants of propagation. It results in mutual shifting of these two modes and linear polarization becomes elliptical. In the multimode waveguide, the situation is even more complicated, because all modes are coupled with their polarizational counterparts and the resultant state of polarization is random, resembling this of the noncoherent light. This tendency toward the change of polarization strongly increases in case of a weak anizotrophy, caused for instance by a stress in the core.

3.3. Amplitude transducers

There can be distinguished three main types of transducers in which the optical wave is amplitude-modulated. These are devices: with noncontinuous luminous flux, without cladding or specially refractive-index profiled and piezoabsorbing. In a transducer with the dissected fibre the ends of two lightguides are closed in a small package. The action of an external force causes these end-faces or special membrane to move in this way that the optical signal changes together with the changes of the force. The characteristics of such transducers can be linear in a very broad range of dynamics. Depending on the internal pressure in the capsule, the device can measure practically arbitrary forces. This converter can find the application in fibre-optic tonometres, pressure measuring equipment in inaccessible places.

The fibre without the cladding is considerably more sensitive to external actions than the fibre covered with the optical cladding. The losses per unit length depends strongly on random bendings, also on the changes of refractive-index of the surrounding medium. Thus, if it is possible to convert the measured quantities into two mentioned parameters: bendings and refractive-index changes, the fibre will be exceptionally accurate measuring converter. Let us assume, that the fibre without the

cladding is immersed in a fluid of medium refractive-index n . If there is propagated an acoustical wave in this fluid, there will be created periodic perturbations of the refractive-index around the fibre and the optical power will flow out of the guide. The acoustical wave will create certain analogue of a diffraction grating. As an additional effect there will appear the phase modulation due to simultaneous vibrations of the fibre itself. It is apparent, that the fibre can work as the amplitude, as well as phase hydrophone. In order to form suitable work characteristics, the refractive-index profile of the fibre can be designed accordingly to even sophisticated needs. And so, the most sensitive to the bendings will be the step-index fibre, less sensitive the fibre with W-profile. The sensitivity of the transducer will depend, in the greatest degree, on the shape of this part of the refractive-index profile that creates the core-cladding boundary.

In the next class of amplitude transducers - piezoabsorption ones, the external measured quantity acting on the fibre causes the absorption edge of the guide's material to be shifted in the wavelength's domain.

3.4. Phase transducers

The acoustical wave propagated along an optical fibre makes it vibrate. Each of vibration modes has dispersion properties and also has its cut-off frequency, above which it is impossible to excite this mode. Not far from the cut-off frequency of the vibration mode the wavelength in axial direction is very great and the whole cross-section of the fibre is stressed. When the frequency increases, the axial wavelength decreases and the acoustical mode takes the shape of a surface wave. Hence, can be inferred that light propagated along the fibre will be strongly phase-modulated near cut-off of the acoustical mode and then this modulation weakens together with the acoustical frequency increase. This modulation will be different for various modes. Additionally, as it was shown, the acoustical wave will induce strong mode coupling between optical modes whose beat length is close to the wavelength of the acoustical wave [2].

When a fibre is subject to the longitudinal stress, there exist three main effects leading to the phase's change of the optical

carrier: change of fibre's length - dominant effect, change of diameter - can be omitted, refractive-index change - elastooptical effect. In a laboratory practice the mentioned effects can be obtained /for instance for transducer's characteristics investigations/ in a fibre by means of simple piezoelectric converters, which can stress the guide in axial direction, as well as centricly.

3.5. Transducers with additional active medium

The general idea of the construction of fibre-optic transducers with active medium is the participation of this additional factor in the process of interaction between the measured process and optical wave. This factor can be combined with the waveguide as well as with the measured object.

Fibre-optic heads found broad application in precise scyntillographic and spectrofotometric equipment. The lightguides, made of suitable plastics, ended with micro-capsules filled with phosphorus, are used for detection of ionization radiation. The luminescence of phosphorus, proportional to the intensity of gamma radiation, is sent by means of the guide to an external counter. Such miniature probes can be extremely useful for instance in oncology.

Fibre-optic termometric probe is constructed in a similar manner. The endpiece of the device is equipped with small capsule containing the liquid cristal, the reflectivity or transparency of which depends strongly on the temperature. The amount of reflected or transmitted light displays the temperature. The change of the range can be obtained by suitable choosing of the capsule. Such a device measures the temperature with great accuracy approximately 0.01°C , but with small long-term stability and in comparatively narrow window from 10°C to 60°C . Basical facility of this device is that it is very small and **does** not change the entropy of the process under control.

Another, and very interesting example of fibre acousto-optic transducer with the active medium is so called Bell photophone. The optical power carried by the guide is directly changed into the acoustical power. The guide is now ended with the capsule filled with the gas mixture of specially chosen components. The pressure changes in this capsule, under the influence of

optical power. The changing pressure is transformed by means of long tube gas acoustical transformator and sets in motion the membrane of a microphone. It is possible, due to this device, to construct wholly optical telephone, in which the electrical current is needed for supply of the optical source.

The fibre-optic fluoresceinoscope is an example of the transducer with active medium combined with the investigated object. the investigated place is injected with the fluoresceine, which is randomly distributed in pits, cracks, etc. The distribution of the luminescence of the fluoresceine /activated simultaneously by UV radiation/ is observed and collected by small fibre probe.

4. Applications' considerations

The attention ought to be focused on the important matter of construction of integrated and homogeneous automatic measurement systems. Such systems can be generally presented as a feedback between the observer and the transducer cooperating with the measuring part of the device and the executing part. The mediator in this process, giving out an opinion /meaning here additional information in feedback link/ can be a scientist or this mediator can be realised automatically by a computer. It can be shown, that optical fibres and fibre-optic technology can find applications not only as transducers for controlling of broad spectrum of processes but also as signal guides in the feedback path and as elements of the executing device. The possibility of realization of the whole complicated control-measurement unit in one technology in the optical system gives integrated optics. Integrated optics operational devices or semiconductor VLSI microprocessors can be comparatively easily put in the feedback path of this complex fibre-optic system. Giving out a lot of pieces of information the integrated fibre-optic probe /performing many simultaneous measurements/ could appear to be hard to explicit usage. It seems, that introductory information processing can be performed by suitable microprocessors. In the first stage, the role of this processing would rather be passive and would consist in facilitating of diagnostic process. Additional facility of building such integrated systems is that fibre-optics needs no complex interfaces to work together with integra-

ted optics and only simple optical repeaters to work with VLSI microprocessors.

There exist great possibilities of applications of precise, holographic micro-endofiberscopes of special construction in the diagnostic and surgical ophthalmology equipment. The application of this type of precise and miniature probes can extend the operational possibilities of a physician. A few words is worth to devote to the character of ophthalmology apparatus utilizing optical fibres. All perforations of the eye globe had the traumatic nature, so applied in the fibre probe the measuring transducers, illuminators: active /with laser source/ and passive /with cold source/ or imageguides have to have as small dimensions as possible. Because of this, there can be considered only very thin fibres of the diameter equal to a few micrometers. Managing with the bundle of several thousands of such fibres is technologically difficult. Due to the character of the ophthalmological operational field, there can be used rigid probes, possessing rigid imageguides constructed of the single fibre and suitable length and properly chosen refractive-index profile. By means of this oculoscop there can be fulfilled observations and operations of the retina in case of the cataract. It concerns specially pathological states in which appear vitreous-retinal adhesions threatening the detachment of the retina.

The lacrimal ducts are narrow, fairly tortous and cushioned with delicate epithelium, therefore the application of a suitable, flexible and extremely thin probe with illuminator /produced nowadays the thinnest imageguides, made of the single "selfoc" fibre of specially graded refractive-index profile have the diameter less than 0.5mm/ would permit for nontraumatological examinations. This ducts can be closed or narrowed on various levels by reason of inborne or morbid factors. The patency of this ducts is obtained now by probing them without the visual control or by operating on them with opening of sac lacrimal through the skin. Probing with the visual control gives the possibility to avoid making a false way or randomly hurt their delicate screens or mitrals of the sac lacrimal. The hurtings of the lacrimal ducts result often in stenosis neglecting the flow of tears, thus favoring the infections. Due to the introduction by

the anatomical ways the cutting and coagulating probe, the process of making a free passage would become more precise and less traumatic. The abovementioned possibilities of the microprobe would partially permit to resign with the aid of the harmful X-ray technique.

Further completion of the probe consists in adding to it, apart from the illuminator and imageguide also the transducers. The illuminator plays a double part in such microprobe: passive - it facilitates the observations carried out by the lightguide, and also active - for performing of therapeutic treatments like photocoagulation. Additionally, the package of the probe, ie. metal needle, can be used for electrocoagulation or obtaining the state of hiperthermy. The properties of an optical fibre of specially shaped refractive-index profile can be applied for simultaneous performance of various measurements eg: opto-acoustical or optical holography, opto-acoustical investigations of vibrations of biological objects, blood's flow measurements, colorimetry, oximetry, chemical compositions' measurements, internal pressures' and temperatures' measurements, internal observations, optical diagnosis, therapy and stimulation.

The next stage of the completion is the supply of the probe with an optical system which enables the accomplishment of photography also in holographical way. In this case, suitably shaped refractive-index profile of the fibre can additionally serve as a phase corrector by holographic observations. The combining of laser technique, fibre-optics and holographic methods can open new possibilities in diagnostics. The output face of an illuminating optical fibre, in a holographic micro-endofiberscope, can serve as a reference source by registration of the hologram as well as by its reproduction. The possibility of easy performing of the holograms inside the organismus of a man, not only inside caves of the body, but also inside living tissues, is by means of combining abovementioned techniques available. Fibre-optics micro-holography is a quite new technique and it should be here, one more time, emphasized, that the most important problem is how to combat the phase distortions.

Extremely interesting and mostly unexpected applications fibre micro-probes have found in certain dendrology investigations [3].

Light of specified spectral parameters and photoperiod play a basic role in the regulation of plant growth and development. Light stimuli are accepted in plants by leaves or apical meristems covered by bud scales. Role of these scales as filters of sunlight reaching growth apices is practically unknown. Optical fibres create completely new research possibilities in this field. In 1978 attempts were made at the Institute of Dendrology of the Polish Academy of Sciences, to utilize optical fibres in physiological studies on the development of apical domes in forest trees. The research is being conducted along a few lines: locating of short segments of fibres into buds, supply of light inside the buds, the analysis of natural light conditions existing inside buds.

Hydrometric measurements comprise quantities like: volume, capacity, pressure, velocity, intensity, flow, temperature, density, concentration etc. The aqueous measurements, specially at the presence of turbulent flows /random fluctuations of hydro- and termodinamic parameters/ demand simultaneous control and recording of many parameters. This leads to the necessity of using a great number of various sensors. The traditional, mechanical or electronic sensors are comparatively big, change the conditions of the flow, display mutual influences and considerable sensitivity on the stage of pollution and temperature variations. The fibre-optic sensors are more sensitive, more immune against water environment, give larger measuring possibilities. The application of fibre-optic micro-transducers, through the possibility of integrated and simultaneous measurement of many values, gives the chance of better understanding of turbulences phenomena, which are so important in the process of energy transportation, diffusion of pollutions, etc.

The miniature fibre-optic transducers have found the applications in the investigations of the normal, pre-tensioned and reinforced concrete. Suitable placing of optical micro-transducers in the armoured concrete allows: to trace the cooperations between the concrete and the reinforcement, allows to trace the change of internal tensions due to the temperature changes. Connection of such a net of sensors /placed for instance in a big water dam/ with an automatic recording and information processing sy-

stem let the operator obtain the actual state of an object.

5. Conclusions

It is rather difficult to show consizely all possible solutions of the constructions and the possibilities of applications of the fibre-optic micro-systems. The general idea, however, of investigations of inaccessible areas with the aid of fibre-optic technique was outlined. The main goal at which this idea aims is: quick and precise measurement, increase in possibilities of investigations, making the whole measurement system homogeneous [4].

The main facilities of fibre-optics are: comparatively low cost, low material consuming technology, high stage of homogeneity and compactness, great possibilities to participate in integrated micro-systems steered by micro-processors or computers.

References

- [1] D.Marcuse, Theory of dielectric optical waveguides, Acad. Press, New York 1974.
- [2] D.Howard, T.J.Hall, Interaction of high-frequency sound with fibre-guided coherent light, Electron. Lett., vol.14, no.19, 1978, p.620.
- [3] W.Chażupka, M.Giertych, Possible use of optical fibres in studies on the physiology of bud development in woody plants, Sec. Nat. Symp., Optical Fibres and Their Applications, Jabłonna 1979.
- [4] A.L.Harmer, Optical fibre transducers for instrumentation applications, Proc. of Battele Res. Centre, Geneva 1979.