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Dear Reader,

This is number 35 of UNIDO's state-of-the-art series in the field of materials entitled *Advances in Materials Technology: Monitor*. This *Monitor* is devoted to **SENSORS AND THEIR INDUSTRIAL APPLICATIONS**.

The main article for this *Monitor* was written for us by Peter A. Payne of the Department of Instrumentation and Analytical Science, University of Manchester.

We invite our readers to share with us their experience related to any aspect of production and utilization of materials and especially comments on the subject of this *Monitor*. It will be appreciated if you answer the few questions on the "Reader survey", which you will find at the end of this *Monitor* and return to us. Thank you for taking your valuable time.

Investment and Technology Promotion Division

CONTENTS

1. ULTRASONIC TRANSDUCERS: DESIGN, CONSTRUCTION AND APPLICATIONS

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ABSTRACT

In the last twenty years or so applications of ultrasound have increased enormously. This is true of both industrial and medical applications. Indeed, in the medical field, ultrasound is now the most used imaging modality, having pushed X-ray imaging into second place in the last year, according to information from one of the major medical imaging companies. The tremendous strides that have been made in medical ultrasound owe much to the application of image processing and microelectronics technology. However, the ultrasound transducer is almost always the limiting factor in extracting better performance from an imaging system. This being so, it is appropriate to concentrate on the design of ultrasound transducers if improvements are to be obtained.

If the physical limitations to the extraction of information using ultrasound are examined, then it is seen that there is still tremendous scope for improvement in terms of the materials used for ultrasound transducers and in the overall design of their structure. This accounts for the very considerable research effort world-wide.

In these notes we begin by reviewing some fundamental aspects of ultrasound and then consider the design aspects of single-element and multi-element ultrasound transducers. Finally, some indications of application areas for such transducers are provided, together with a brief review of very recent developments.

KEYWORDS

Acoustic impedance; applications; arrays; attenuation; ceramics; composites; compressional waves; ferroelectricity; instrumentation; integrated arrays; Lamb waves; mode conversion; piezoelectricity; polymers; radiation pattern; scattering; shear waves; ultrasound transducers; wave propagation.

INTRODUCTION

Ultrasound, which is by definition sound above the range of frequencies audible to the human ear (i.e., above about 15 to 20 kHz) is a common phenomenon in nature. Many animals use it as a means of communication and location of prey and this is true of both land animals, such as insects and bats, and some of those living under water. Ultrasound is also generated by many common processes, many of which, like the steam whistle, generate audible sound and copious volumes of ultrasound. Indeed, one of the advantages claimed for our use of ultrasound for measurement or other purposes is the fact that we cannot hear it.

In these notes a brief review of ultrasound fundamentals will be provided in order to set the scene for the main subject, which is the design and application of ultrasonic transducers.

This is a most appropriate time to review this topic since there have been quite major advances in the area in the past few years, some of which will be covered later.

Applications of ultrasound can be conveniently divided into low and high power. Low power, or low intensity, applications can also be described as diagnostic applications and these typically employ only milliwatts of average ultrasonic power, and by definition do not permanently change the medium through which ultrasound is propagated or the characteristics of the subject of measurement. Examples of applications in this area are non-destructive testing or evaluation (NDT or NDE) and medical diagnosis. In contrast, high power ultrasonic techniques are intended to make a permanent change to the state of the material being treated. Applications in this category are typified, for example, by the welding together of two materials or descaling of human teeth. The high power applications of ultrasound and the transducers that are required for this will be treated in less detail in these notes than the purely diagnostic techniques.

ULTRASOUND FUNDAMENTALS

Wave Propagation and Mode Conversion

Ultrasound is a form of mechanical energy, which propagates by means of the particles in a medium, which are themselves vibrating, transmitting some of the vibrational energy onto neighbouring particles. From this it is clear that ultrasonic energy cannot be propagated through a vacuum and that it propagates more readily through solids than through liquids or gases. Indeed, the velocity of propagation generally rises as we go from gaseous through liquid to the solid state. In the solid state, however, the situation is much more complicated since it is possible for not only longitudinal or compressional waves to propagate, but also many types of shear wave. Of course, shear waves will not propagate in liquids and gases since these media do not support shear forces.

Longitudinal or compressional waves are characterized by the vibrational direction of the particles being in the direction of propagation of the wave. However, shear waves can have the vibrational direction at any angle with respect to the direction of propagation, and can therefore be polarised. An additional complication arises at the surface of a solid where many forms of shear wave can be propagated, but in addition, the so-called Rayleigh wave can occur. This is a wave in which the motion of particles is in an ellipsoid shape, and in general gives rise to a slower velocity of propagation. If we take a material such as aluminium as an example, then the compressional, shear and Rayleigh velocities are as given in table I (see page 11).

A further wave motion that is of some importance, particularly in NDT, occurs in layers of material or in plates. These are sometimes known as plate-waves, but are more properly referred to as Lamb waves. Two forms of such waves exist: the symmetric and the asymmetric, both of which occur in various orders. Further details on Lamb waves and their use in materials testing are given in Krautkrämer and Krautkrämer [2].

Reflection, Transmission and Refraction at Boundaries

In some ways, the behaviour of an ultrasound wave when it meets a boundary between two materials can be thought of as similar to that of light rays. In particular, Snell's Law applies and if we take as an example the situation shown in figure 1 (see page 13), then using Snell's Law we see that:

$$\frac{\sin\alpha}{\upsilon_{C1}} = \frac{\sin\beta}{\upsilon_{S1}} = \frac{\sin\gamma}{\upsilon_{C2}} = \frac{\sin\delta}{\upsilon_{S2}} \qquad (1)$$

where the angles α, β, γ and δ are defined in figure 1; υ_c and υ_s refer to compressional and shear velocities, respectively; and subscripts 1 and 2 refer to the two materials.

Of course, figure 1 assumes that both media are solid and therefore support shear waves. If Medium 1 was a liquid, then there would be no reflected shear wave. This is in fact a very common occurrence in using ultrasound for the examination of materials. It is fairly common to use a so-called immersion probe and to scan the material to be examined with ultrasonic energy under water.

It should also be clear from figure 1 that as the angle α is increased, a point will be reached where only surface waves are propagated in Medium 2. This is the basis for generating surface Rayleigh waves and Lamb waves using a compression wave propagated through a suitably angled solid wedge.

Ultrasound is also very frequently used as the basis for diagnostic techniques in medicine. In most cases, cross-sectional images of the ultrasonic properties of biological tissue are produced and this is done either by the use of transducers in contact with the skin or through a small water bath stand-off. In either case, we see that for medical ultrasound imaging the complication of shear waves does not usually exist, since the soft tissues of the body behave very much like water as far as ultrasound energy is concerned. There have been reports of some experiments in which shear waves have been used for measurements of the properties of bone.

Acoustic Impedance

The pulse echo method of examining materials has already been alluded to and for this technique to be of practical use to us, it requires that when ultrasound meets a boundary between two media, some of the energy is reflected and some travels on. The degree to which these events happen depends on the difference between the acoustic impedance (more correctly, the specific acoustic impedance) of the two media. Impedance has the dimensions of pressure divided by velocity and in terms of acoustic energy, the dimensions are kgm^2s^{-1}. As in electrical impedance, acoustic impedance is really a complex quantity, but the literature usually quotes values for the real part of this quantity, $Z = \rho c$ where ρ is the density of the material and c the velocity of acoustic energy in the material. Thus, with knowledge of these material constants, it is relatively simple to calculate the reflectivity of an interface, since in terms of intensity and assuming normal incidence, the ratio between incident, reflected and transmitted intensity is given by the following equations:

$$\frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \qquad (2)$$

$$\frac{I_t}{I_i} = \frac{4Z_2Z_1}{(Z_2 + Z_1)^2} \qquad (3)$$

where I_r, I_t and I_i are the intensities of the reflected, transmitted and incident waves; Z_1 and Z_2 are the acoustic impedances of the two media.

Clearly, if there is a large difference between the two acoustic impedances, then the acoustic energy is completely reflected.

Attenuation and Scattering

As ultrasound energy is propagated through a medium, a number of energy conversion processes will occur and gradually the ultrasonic intensity of the propagated wave will diminish. In addition, if the wave deviates from a truly parallel beam, then the intensity per unit area is also reduced. The major energy conversion process is usually that of absorption, which converts the ultrasound energy into thermal energy. However, if the medium is characterised by small non-specular particles, then considerable energy loss due to scattering will also occur. This is true for materials such as concrete where the aggregate contained acts as scatterers. It is also true for certain types of stainless steel and for blood, where the major source of scattering is through ultrasonic interaction with red blood cells. In many cases, the effect of scattering is such as to almost preclude useful measurement activity, but, for example, where the scatterers are moving, such as red blood cells in the blood stream, the scattered ultrasonic energy contains useful data on the velocity of the blood.

Another form of energy loss is associated with mode conversion, so that if interest is largely centred on the passage of a compressional wave through a multi-layered medium, the ultrasonic signal received as a result of transmission, refraction and/or reflection may be much reduced in intensity and much more complex due to the arrival times of numerous mode-converted shear and compressional waves. Successful use of ultrasound in such circumstances depends very much on a complete understanding of the various conversion mechanisms that occur.

If we consider the sound pressure of a plane wave subjected to attenuation, the following expression applies:

(4) $$p = p_0 e^{-\alpha d}$$

where p_0 and p are the sound pressures at two points in the line of propagation separated by the distance d. α is the attenuation coefficient, which is often quoted for intensity rather than sound pressure. In this case, the expression becomes:

(5) $$I = I_0 e^{-\alpha_I d}$$

Now, since intensity is proportional to the square of the sound pressure, then we have:

(6) $$e^{-\alpha_I d} = e^{-2\alpha d}$$

thus:

(7) $$\alpha_I = 2\alpha$$

If we take the natural logarithm of equation (4), we obtain:

(8) $$\alpha = \frac{1}{d} \ln \frac{p_0}{p}$$

This is the true attenuation, or total attenuation over distance d and is expressed in Nepers (Np) per unit distance. Attenuation coefficients are therefore often quoted in Nepers per centimetre. However, more often, the decibel unit is preferred and the conversion from Nepers to decibels is provided by the following expression:

(9) $$\alpha = \frac{1}{d} 20\log \frac{p_0}{p} \qquad \text{(dB)}$$

As an example, water at 20° C has an attenuation or absorption at 4 MHz of 3.5 dBm^{-1}, but there is a frequency dependence and this is:

(10) $$\alpha = 0.22 f^2 \qquad (dB^{-1})$$

where f is in megahertz.

Water is therefore seen to be a very good medium for propagating high frequency ultrasound. However, this simple expression neglects effects that can be caused at very high powers, such as cavitation, which is yet another method of removing energy from the propagating beam.

Table II (see page 11) provides examples of properties of some materials of interest.

Radiation

Ultrasonic energy exerts a static pressure or radiation pressure at any interface or medium across which there is a loss of ultrasonic intensity in the direction of propagation. This pressure is distinct from the oscillatory pressures due to the vibration of the particles in the wave.

If the source of ultrasound energy is small compared with the wavelength in the propagating medium, then the source will radiate with a spherical radiation pattern that is uniform over a solid angle of 4π radians. It should be noted that a radiation detector of a similar dimension will have a sensitivity that is uniform over a solid angle of 2π radians.

The point source generation of ultrasound is relatively unusual, except in very special circumstances and most real sources of ultrasonic energy have an area that is large compared with the wavelength of the ultrasound they generate. In this case it is usual to employ Huygen's principle to develop the radiation field pattern from the face of the source and over the years, numerous authors have published solutions for special cases using either continuous wave (CW) or transiently excited surfaces.

There are still many applications in research and materials evaluation for which simple single element transducers having a circular front face are appropriate. This is one of the simplest of the field patterns to analyse, but even this solution is relatively complex. The derivation involves the solution of a three-dimensional geometrical problem and the beam profile that arises from the solution is usually thought to comprise two distinct regions: the near or Frésnel zone and the far or Fraunhofer zone [6]. Figure 2 (see page 13) illustrates the radiation pattern for a circular disc that is vibrating in a CW sense and behaves as a perfect piston. Figure 2 (a) (see page 13) is a graph of the solution to:

$$\frac{I_z}{I_o} = \sin^2 \frac{\pi}{\lambda} \{(a^2 + z^2)^{1/2} - z\} \qquad (11)$$

As we shall see later, most measurements using ultrasound are conducted in a transient or pulsed mode. It is therefore of considerable interest to know how much the pattern shown in figure 2 changes under transient excitation. This is a more complex computational problem, but solutions have been produced and we should note that the radiation pattern depends to some extent on the nature of the transient excitation. In contrast to the CW condition, the interference patterns that determine the shape of the field may not have time to fully develop under transient excitation and thus the field patterns themselves turn out to be somewhat simpler. An illustration of the difference between CW, pulsed CW and short pulse excitation is given in figure 3 (see page 14).

So far we have considered sources that are circular in cross-section. Because of the manner in which interference effectively determines the shape of the radiated field, it should be clear that if we choose a rectangular cross-section as the source of the ultrasound field, it will change the radiation pattern we produce. For CW excitation, figure 4 (see page 14) compares the radiation pattern along the central axis of a radiated field from a perfect piston, which is either circular or square in cross-section. As can be seen, there may be some advantage in using a rectangular cross-section, since the changes in intensity in the near-field and close to the transducer are somewhat reduced.

Most medical ultrasound transducers are multi-element in structure and the elements are usually rectangular in cross-section. Multi-element transducers will be considered in detail later.

If the surface from which the ultrasound field is developed is, for instance, shaped into part of a sphere, then we obtain a self-focusing effect that can be achieved at any position within the near-field of the equivalent flat source and down to the radius of the sphere. Figure 5 (see page 15) illustrates this concept. The ellipse shown in this figure represents the focal region that can be achieved, since in practice a point focus is not possible. The width and length of the ellipse, W and L, depend on the radius of curvature and wavelength, and approximate figures are given in Wells [6].

As in the optical equivalent, we can also produce focusing effects with acoustic lenses and this is done by the appropriate choice of acoustic impedance of the lens and the medium into which the ultrasound is to propagate. Figure 5 can also be interpreted to show the effects of an acoustic lens system. Numerous other focusing systems have been derived, most of which are based on the equivalent optical scheme. Acoustic or ultrasonic mirrors are also feasible and have been much used in miniature rotating transducers designed for medical applications.

TYPES OF SENSOR

Piezoelectric and Ferroelectric Effects

The piezoelectric effect is of great importance in ultrasonic transducer design, being the most widely used effect for the generation and detection of ultrasound.

The phenomena of piezoelectricity was first observed in quartz crystals by the Curie brothers in 1880. They described the so-called "Direct Piezoelectric Effect" whereby an electric charge appears on the surface of a solid when it is subject to mechanical stress. The "Converse Piezoelectric Effect" occurs when an electric force applied across a solid produces a change in dimensions. This effect only occurs in crystals with no single centre of symmetry, so that the effect varies for different axes. Thus the solid used for an ultrasound source can be crystallographically arranged in such a way that application of an alternating electric field between two faces can cause dimensional changes either in parallel or transverse to the direction between the faces. In quartz, the crystal can be cleaved along certain faces to give slabs of crystal with their large faces perpendicular to any one of at least three axes of symmetry - the so-called X-cut, Y-cut or Z-cut. Each cut produces electrical charges on faces at different orientation to the direction of applied stress or tension.

Many ceramic materials exhibit piezoelectricity, and are widely used to make ultrasonic transducers. The electric field is usually applied to the ceramic by two electrodes, one on each surface with a defined relationship to a piezoelectric axis. Thus the application of the electric field produces a well defined and predictable change in a specific dimension of the transducer, which causes the surrounding medium to change density in sympathy. This is how the transducer changes the incoming electrical excitation to mechanical (sound) energy.

The piezoelectric (pressure-electric) effect is a general name for any mechanism that relates electric excitation to changes in dimensions or stress in a material. The mechanisms of this relationship may not be linear.

Ferroelectricity

The definition of ferroelectricity is a reversibility of the direction of the electric dipole in a polar crystal by means of an electric field. The most obvious analogue is that of ferromagnetism when the same effect is caused by a change in the magnetic field.

In a ferroelectric dielectric polarisation is due to the alignment of dipoles. This polarisation is stable because of the strong interaction between these dipoles. The dipoles can be aligned in the first instance by elevation of temperature and application of strong external electric fields.

The most commonly accepted criterion of ferroelectricity is a graph of electrical displacement *D* measured in charge produced per unit area of surface against applied electrical field strength *E* measured in applied potential per unit length normal to the surface. If this graph shows a hysteresis or memory effect, then the substance can be said to exhibit ferroelectricity (see figure 6, page 15).

The importance of ferroelectricity is that it allows the polarisation of many substances to be accomplished in a controlled manner by means of application of external electric fields. This produces an anisotropic substance that exhibits piezoelectricity. The anisotropy can be "frozen" in certain materials by reducing their temperature. The temperature below which the polarisation is frozen in may be as high as 450° C, so many substances are stable at room and common industrial temperatures.

Transducers Based on Piezoelectric Ceramic Materials

Probably the earliest of the piezoelectric ceramics was barium titanate, a polycrystalline ceramic having the composition $BaTiO_3$. However, other materials have been developed and the most popular of these is a solid solution of lead zirconate and lead titanate. This has a much higher Curie point (320 to 350° C) than barium titanate and its piezoelectric coefficients can also be tailored to make it out-perform barium titanate.

In fact, lead zirconate titanate is commercially available with many added minor constituents, which are not disclosed by the manufacturers. Anyone wishing to manufacture their own ultrasound transducer needs to wade through enormous volumes of measurement data in order to choose the most appropriate material from the wide range available commercially.

For single element transducers applied in NDT or medicine, the active piezoelectric element is usually a circular disc, the diameter of which will vary according to application and the thickness is defined by the vibrational mode and whether the disc is in half-wave or quarter-wave resonance. In some cases, harmonics of the fundamental resonance mode are selected and this is particularly true when very high frequency ultrasound is to be employed. Detailed design considerations for transducers in the NDT area can be obtained from Silk [7]. Piezoelectric transducers based on ceramics are also widely used for the detection of vibration - the so-called seismic accelerometer. For detailed information of the design of these devices, reference [8] should be consulted.

Figure 7 (see page 16) shows the constructional details of a simple ultrasound pulse echo transducer in cross-section.

Attached to the two faces of the active element, the piezoelectric material, are electrodes, which ensure that in transmit the electric field is efficiently coupled to the piezoelectric material and in receive the mechanical-to-electrical conversion that must take place is efficiently detected. Wires are attached to the electrodes that go back to the instrumentation. Also attached to the rear face of the active element is the so-called backing material. The purpose of this material is to absorb the backward going wave, which would otherwise possibly reflect off the interior structure of the transducer housing and be sensed as a spurious echo during the receive period of operation. Careful consideration of the characteristics of this backing material enable the designer to produce either a very wide band, but perhaps a relatively poor sensitivity device or a narrow band, but a rather better sensitivity device. On the front face of the transducer a matching layer is often employed. This layer is a quarter-wavelength thick and enables much more efficient coupling of ultrasound from the active piezoelectric element into the medium of interest. For contact scanning of engineering materials, the transducer is usually protected with a so-called rubbing face and brought into contact with the structure to be examined via a thin film of oil.

Matching layers inherently make the transducer more narrow band and to counteract this effect, two or more layers can be used, each of which is about a quarter-wavelength thick, but at different frequencies. Various approximations are available in the literature to guide the designer on the choice of matching layers. The whole subject has become another one of these in which manufacturers jealously guard their own secret recipes.

Although there are still a few applications for single element transducers in the medical ultrasonics field, mostly these days transducers comprise multi-element arrays. A diagram of a part of a typical medical ultrasound array is shown in figure 8 (see page 16). The design approach to choosing the thickness of the active elements and their other geometries has been the subject of numerous publications, the best of which are probably still references [9] and [10].

Piezoelectric Polymer Transducers

Many polymeric materials exhibit a degree of piezoelectric activity. Perhaps surprisingly, this includes most of the biological polymers. However, in 1969 Kawai [11] demonstrated a comparatively strong piezoelectric effect from a material known as polyvinylidene fluoride (PVDF or PVF_2). Since then an enormous research effort has been devoted to enhancing the piezoelectric effect and understanding the mechanisms by which the effect is obtained. At present, the most effective polymer in commercial production is a copolymer of vinylidene fluoride (VDF) and trifluoroethylene (TrFE) [12]. Just recently, an alternating copolymer of vinylidene cyanide and vinyl acetate has been developed and this is reported to exhibit activities that approach the PVDF-TrFE copolymer activity [13].

A major advantage that accrues in using materials such as PVDF for ultrasound transducers is that its acoustic impedance is reasonably close to that of water and water is the most commonly used coupling fluid for ultrasonic measurements, be they industrial or biomedical. However, when it comes to multi-element transducer design, a further advantage of the polymer piezoelectric materials is that the elements themselves can be defined simply by using photolithography and vacuum deposition techniques. This is in contrast to the high precision machining required to define elements for ceramic multi-element transducers. Whilst this is not a problem at frequencies up to about 10 MHz, for anything much in excess of this, the machining process is highly complex and the yield of good multi-element transducers consequently suffers.

Integrated Multi-Element Arrays using Piezoelectric Polymers

There is considerable interest world-wide in using ever higher ultrasound frequencies for imaging, both in medicine and in NDT and NDE. As indicated above, difficulties are encountered in manufacturing multi-element arrays at frequencies much in excess of 10 MHz if the commonly available ceramic materials are employed. The ease with which this can be overcome by adopting piezoelectric polymers has been discussed elsewhere [14]. A further problem that must be addressed in designing transducer arrays for operation at frequencies around 20 MHz and higher is that of the cables used to connect each individual element to the electronic system. It is common practice to employ cables of a multi-wire nature several metres in length to facilitate these connections, and at the frequencies now being considered, this proves a considerable disadvantage. Primarily, the problem arises from the relatively high capacitance of such a cable, especially when compared with the capacitance of the very small individual array elements being considered. Dimensions of these are usually 25 µm by a few millimetres in length and when this is taken together with the very low value of permittivity for the material, the scale of the problem can be envisaged.

The alternative approach to the design of very high frequency multi-element ultrasound array systems is to bring the electronic drive and receive circuitry into the case containing the array elements themselves. An approach to this has recently been described [15]. In this case, a set of application-specific integrated circuits (ASICs) have been designed, capable of driving 32 elements of an array. This ASIC chip set can easily be duplicated to enable multiples of 32 elements to be dealt with. The performance of this chip set is outstanding, giving rise to a 1 ns time resolution and a dynamic range for time resolution of 2^{19}. Incidentally, this dynamic range can be easily extended. The current design of the chip set occupies a chip area of 64 mm^2. Work on producing a chip set capable of undertaking the receive electronics requirements for high frequency arrays is under way. It is interesting to note that the approach adopted produces a generic design and that the drive and receive ASIC system will be capable of dealing with multi-element ceramic and polymer based transducers. A further extension to this approach will enable two-dimensional arrays to be employed which will facilitate three-dimensional or volumetric scanning in due course.

Figure 9 (see page 17) is a diagrammatic illustration of the way in which the multi-element package forming the subject of reference [15] is assembled and in figure 10 (see page 18) a photograph of a typical 64-element array package is shown.

Piezoelectric Composite Materials

The enormous advantages of having a piezoelectric material that is well matched to water have led to many researchers considering so-called composite materials. These are materials in which an active ceramic piezoelectric is combined with a passive polymer material, thus giving rise to an overall acoustic impedance which is much lower than that of the ceramic. At the same time, the piezoelectric properties of the ceramic are almost preserved. Whilst in theory an enormous range of different patterns of composite structure can be imaged, in practice, the so-called 1:3 composites [13] have emerged as the front runners for pulse echo work. Figure 11 (see page 18) shows the arrangement of ceramic and polymer employed.

The constructional technique is known as the "dice and fill method" [16] and the aim is to produce thin columns of piezoelectric material supported by a soft polymer. The problem with this method is that the machining requirements for the ceramic are even more severe than those referred to above when considering multi-element transducers. The dimensions of each column of ceramic material must be less than a wavelength at the propagating speed within the ceramic and thus the spaces between the columns are sometimes required to be less than 20 μm in width. Whilst it is possible to use the machining techniques developed for dicing semiconductor materials, the demands are enormously high and, once again, the yields must be correspondingly low. Nevertheless, many of the modern medical ultrasound transducers now use these composite materials as their basis.

Smith [13] recently compared the range of parameters for piezoelectric ceramics, polymers and composites and table III (see page 12) reproduces some of his data. As can be seen, the coupling factor k_t is highest for composites whilst $\bar{Z}$ remains reasonably near that of polymers. $Q_{\overline{m}}$, the mechanical damping factor is also not too far from that of the polymers. However, it must be stressed that, at present, we cannot achieve all the advantages in one material combination. Trade-offs have to be made.

TRANSMIT AND RECEIVE INSTRUMENTATION

The majority of applications of ultrasound in a diagnostic sense employ some form of pulse echo technique. For this it is necessary that a fast electrical pulse be generated and applied to the ultrasound transducer. For applications in which high resolution measurements are required, the electrical drive pulse needs to be either a very fast rising or falling edge, or a very fast impulse.

Using a mathematical modelling approach, it can be shown that the shape of the driving pulse has a significant effect on the acoustic signal that is generated [24]. In the past, considerable work was done on attempting to tailor the shape of the drive pulse to the transducer in use in order to produce an optimum acoustic signal.

Figure 12 (see page 19) shows a simple avalanche transistor based switching circuit capable of producing drive pulses with rise times of the order of 20 ns. With care in design and layout, even better performance than this can be obtained.

If the same transducer is used for both transmit and receive, then steps must be taken to prevent the high voltage drive pulse (anything from 100 V to 1,000 V can be used) from damaging the sensitive receive amplifiers that are needed. The requirements on the receiver instrumentation are that the bandwidth is wide enough to preserve the shape of the original acoustic pulse as far as possible and that the gain be such that echoes arising from small structures and amounting to only microvolts in amplitude can be seen on the display. Fortunately, operational-amplifier technology has developed so well that there is a reasonable choice of packages commercially available, originally designed for the communications industry, which can be employed. The most common form of protection for the input end of the instrument is provided by a back-to-back diode arrangement, as shown in figure 13 (see page 19). The overall arrangement for a simple A-scan pulse echo system is shown in figure 14 (see page 19).

Whilst the principles of the instrumentation for transmit and receive are simple, when we consider the requirements for multi-element systems, the complexity of the electronics required increases enormously. Recently, attention has focused on the use of much higher frequency ultrasonic systems, both for industrial measurement and medicine. This is essentially a requirement to improve resolution of measurements, but it adds enormously to the design problems associated with the electronics.

OTHER TYPES OF ULTRASOUND TRANSDUCERS

For somewhat lower frequencies than have been discussed so far, the magnetostrictive effect can be employed. Usually, a magnetostrictive transducer is in the form of a rod or bar acting as the magnetic core within a coil. An applied varying electrical current in the coil produces a variation in the dimensions of the bar, thus transducing the electrical signal to mechanical energy. Magnetostrictive transducers have been used to produce ultrasonic vibrations in various media for agitation and occasionally for resonance testing of materials. Their major use, however, is in low frequency sonar signalling and other high power applications. The magnetostrictive effect does not give rise to very sensitive receive characteristics and thus such transducers are seldom used in the pulse echo mode. The major advantage of magnetostrictive transducers is that they can generate vastly greater power than, say, a piezoelectric transducer.

Another class of ultrasound transducer that has been developed is the electromagnetic acoustic transducer or EMAT. These are devices that rely on inducing a magnetic field in the material under test and an acoustic wave present on the surface of the material will induce a change in the eddy currents in the surface, which can be detected. This clearly requires that the material under test be highly conductive electrically, which places some restrictions on the applications. A major advantage of an EMAT, however, is that it does not require actual contact with the material, although the distance between the transducer and the material under test is usually less than 1 mm.

Other non-contacting methods of using ultrasound have been developed, such as that using a laser pulse and the thermoacoustic effect [25]. In some cases, lasers are combined with EMATs for a totally non-contacting system and there are other instances where lasers are combined with other optical devices such as the Fabry-Perot interferometer.

APPLICATIONS

Industrial Applications of Ultrasound

A number of references to the industrial applications of ultrasound have already been made. A major area is that of NDT or NDE and considerable efforts have been devoted to using ultrasound in this way, particularly in the nuclear engineering industry. Of particular importance is the testing of welds in pressure vessels, the failure of which could lead to great catastrophes.

Another major area in which ultrasound NDT is applied is in aerospace, where once again great catastrophes could occur due to failure of aircraft structures, etc. Much use of ultrasound is also made in other areas of transport, such as railways and ships.

It has been known for a long time that ultrasound can be applied to enhance or produce chemical changes in materials and some process operators employ ultrasound in this way [26].

Detection of Corrosion in Embedded Steel Cables

Many structures used for major buildings, and particularly for bridges, are constructed from concrete reinforced with steel cables. Corrosion of such cables, usually as a result of poor constructional practice, can lead to catastrophic failure of such structures with consequent large-scale loss of life. A technique that can simply and non-invasively detect the onset of corrosion of these steel cables is therefore of paramount importance.

For many years, ultrasound has been used to assess the strength of concrete. However, since this material is so inhomogeneous, containing scatterers ranging in size from less than a millimetre up to some centimetres, ultrasound energy is severely scattered, absorbed and dispersed and ultrasound inspection of concrete is usually limited to a measurement of the velocity of ultrasound linked to the "cure"-state of the material.

Recently, it has been shown [27] that by using careful signal analysis based on digital deconvolution, the corrosion state of the steel reinforcement can be ascertained. This work is laboratory based and in its initial stages, but it is expected that further developments will lead to commercial instrumentation. A block diagram of the experimental system employed to study the result of corrosion using analysis of ultrasonic signals is shown in figure 15 (see page 20). As can be seen, the ultrasound measurement is made in the "pitch-catch" mode with two transducers mounted on the same face of a large concrete specimen (about 1 metre long). Specimens were produced with carefully controlled mixes of Portland cement so that the steel bar embedded within them would not corrode. In addition, certain specimens were cast with the inclusion of a calcium chloride solution known to induce corrosion and comparisons were made between these two sets. The ultrasound system comprised transducers nominally resonant at 200 kHz and the transmitter transducer was excited by a pulser generating a 600 V sharp pulse once per second.

By adopting a complex deconvolution approach to the analysis of the received data, it proved possible to find characteristic signatures for a concrete specimen with a good steel rod embedded and a concrete specimen containing a corroded rod. Figure 16 (see page 20) provides a dramatic illustration of this.

Biomedical Applications of Ultrasound

The first attempts to use ultrasound for measurements in medicine go back to the mid-1950s where a pitch-catch arrangement was applied to detect the midline of the brain in patients with cranial injuries. Shortly after that, attempts were made to image the foetus *in utero* and in the years since, the medical use of ultrasound has become enormous, creating a vast industry world-wide. The improvement in the images that can now be produced is truly astounding and over the past few years a new addition to the armoury has been to add so-called colour flow Doppler information to cross-sectional images. This enables the detection of important diseases such as atherosclerosis which, in the corotid arteries supplying the brain, can give rise to strokes and death.

Just as the detection ability of medical ultrasound has improved enormously in the recent past, so have the more invasive methods of using the technology. There are now commercial systems that can be inserted into the patient's arteries in order to seek out regions of blockage due to deposition of plaque and to then clear these blockages using either miniature surgical cutters or so-called balloon catheters. The invasive use of ultrasound in this way is likely to be much developed over the next five or ten years.

Combined Intra-arterial Imaging and Therapy

The method of imaging and conducting surgery within the artery currently being used suffer from at least one major disadvantage, which is that the imaging catheter has to be withdrawn and the surgical catheter inserted once a stenosis or arterial blockage has been detected. Clearly, this can lead to problems of relocation prior to the surgical procedure. In a recent publication [28] a technique was described in which the ultrasound energy required for imaging is produced by the photothermal effect due to a very short pulse of laser energy. The acoustic source can be either at the end of an optical fibre or at the interface between blood and an arterial blockage. Due to the rapid heating caused by absorption of the laser pulse, mechanical expansion and contraction occurs, giving rise to ultrasonic energy. This ultrasonic energy is propagated back towards the probe where it is detected by a small annular piezoelectric polymer transducer. A simplified diagram showing the arrangement for this new probe assembly is given in figure 17 (see page 21).

As shown in figure 17, once a stenosis or arterial blockage has been detected, it is possible to switch the laser source so that high power laser energy can be directed onto the blockage in order to ablate it. The initial probe assemblies were of a diameter of 10 mm. However, more recently, they have been redesigned and are now down to 3 mm in diameter. This is small enough to enable insertion into large and medium sized arteries. Work of this nature is often carried out on the major arteries such as the femoral in the lower limbs.

An even more ambitious development is associated with a probe assembly that images both forwards and sideways, still maintaining the ability to carry out surgical procedures. Some progress towards such an assembly has been made [29].

The ability to work at higher frequencies and to use much smaller ultrasound transducer assemblies makes it possible to contemplate more extensive use of ultrasound to assist in surgical procedures. New techniques such as keyhole surgery are now very common and are frequently conducted using ordered bundles of optical fibres as a means of illumination and viewing. However, diagnosis of diseased tissue is not always possible using a visible image and the addition of an ultrasound facility as part of a keyhole surgery procedure might prove very effective.

CONCLUSIONS

These notes have introduced the subject of ultrasound and the means by which it can be generated and received. The various physical effects that are employed to manufacture ultrasound transducers have been discussed and the application areas for ultrasound have been briefly covered.

ACKNOWLEDGEMENTS

Figures 15 and 16 are based on work reported in reference [27] and were provided by Dr. P. A. Gaydecki.

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Table I

Velocities of various elastic waves in aluminium.
Note the variation in velocity reported, which is probably dependent on the precise composition of the aluminium tested.

Wave / Source	Velocity, ms^{-1} [1]	[2]	[3]	[4]
Longitudinal	6,420	6,320	6,420	6,374
Shear	3,040	3,130	3,040	3,111
Rayleigh	-	-	-	2,906

Table II

Properties of some typical engineering materials.
Data from [1,3,4,5]

Material	Density (gcm^{-3})	Velocity of Sound (ms^{-1}) C_L	C_S	C_R	Attenuation ($dBcm^{-1}$) (Longitudinal waves)
Aluminium (Duralumin)	2.8	6,374	3,111	2,906	0.40**
Copper	8.9	4,759	2,325	2,171	0.37
Iron (cast)	7.0 - 7.4	4,994	2,809	2,590	0.29
Silver	10.6	3,704	1,698	1,592	0.38
Tungsten carbide	14.2 - 15.0	6,655	3,984	3,643	0.27
Brass	8.4	4,372	2,100	1,964	0.38
Steel (mild)	7.9	5,960	3,235	2,996	0.29
Steel (tool, hardened)	7.84	5,874	3,179	2,945	-
Steel (stainless)*	7.8	5,980	3,297	3,049	-
Glass (crown)	2.5	5,660	3,420	3,127	0.245
Nylon 66	1.12	2,680	1,100	-	11.50**
Polyethylene	0.92	2,000	540	-	0.487

C_L: longitudinal, C_S: shear, C_R: Rayleigh, velocities.

* approximate composition 0.2% C, 0.5% Si, 0.7% Mn, 2.0% Ni, 18.0 Cr.

** Neper m^{-1}.

Table III

Comparison of certain piezoelectric parameters for ceramic polymer and composite materials

Material	Selected Piezoelectric Parameters					
	k_{33} (%)	k_t (%)	tanδ (%)	Q_m	ρ (10^3kgm^{-3})	Z (MRayl)
Barium titanate [17]	48	38.4	0.5 - 0.6	400 - 600	5.55	31.2
Lead-zirconate titanate PZT4 [17]	70	51.3	0.4	500	7.5	34.5
Lead-zirconate titanate PZT5H [17]	75.2	50.5	2.0	65	7.5 - 7.8	33.3
Lead metaniobate EC82 [18]	75	37 - 41	0.9	11 - 110	4.3 - 5.9	30.3
PVDF [19-22]	-12.2	11	1.5	10 - 20	1.5 - 1.8	3.9
P(VDF-TrFE) [22,23]	-22.8	25 - 30	2 - 15	20	1.8 - 1.9	4.1 - 4.5
Piezo-composites [13]	-	60 - 75	<1	2 - 50	2.0 - 5.0	4 - 20

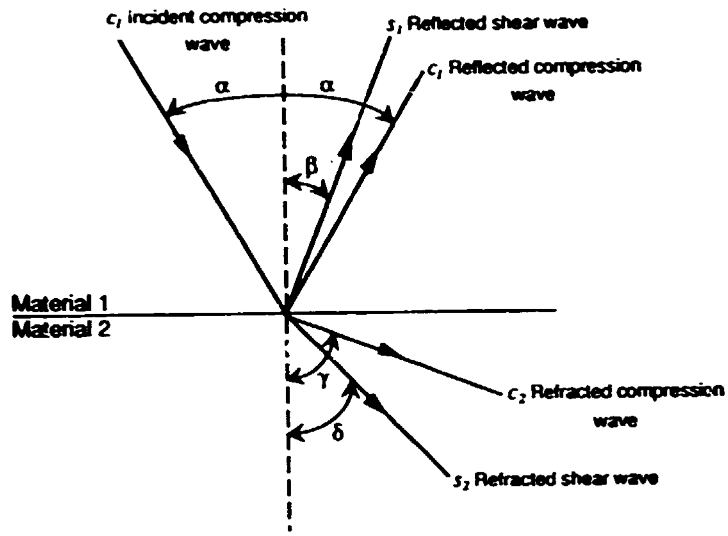


Figure 1

Behaviour of an ultrasonic wave at a boundary between two solids

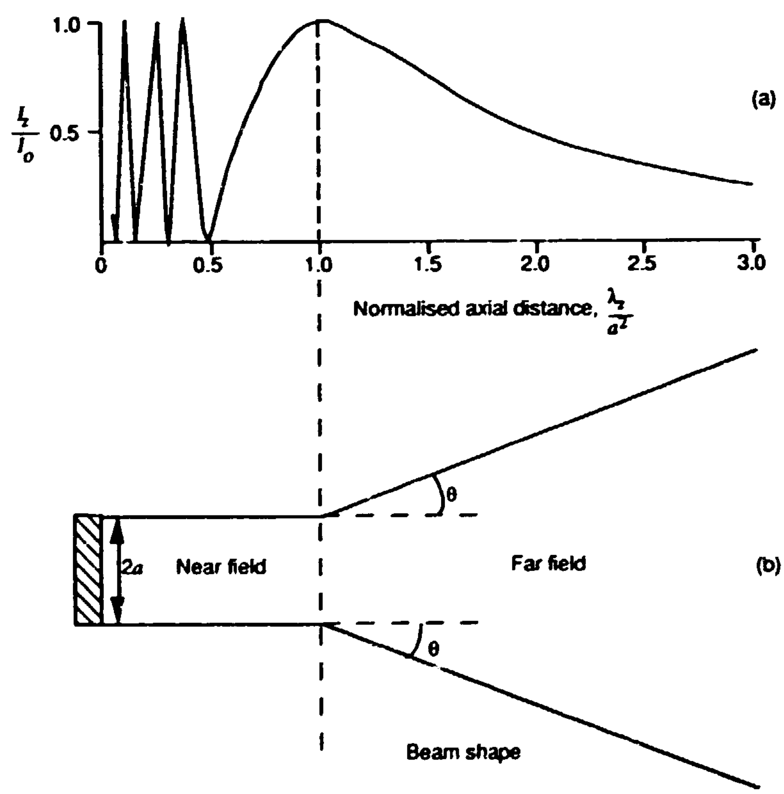


Figure 2

Idealised plot of:

(a) *the intensity produced by a circular piston source along the central axis; and*

(b) *an illustration of beam divergence.*

(Adapted from Wells [6])

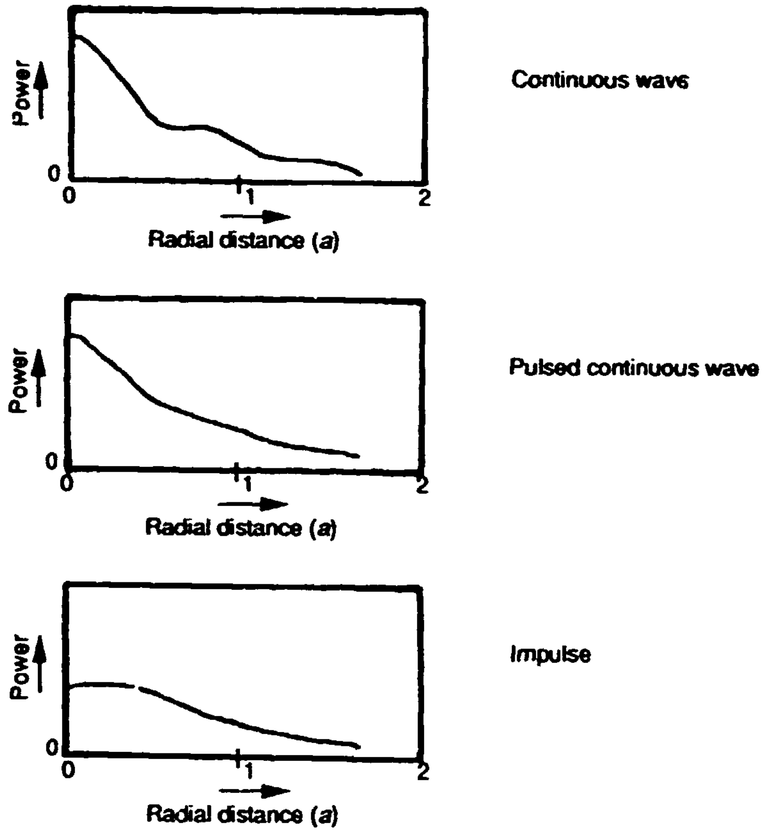


Figure 3

Effect of excitation on field pattern across a vibrating piston at normalised axial distance of $\frac{\lambda_z}{a^2} = 1$.
(Adapted from Wells [6])

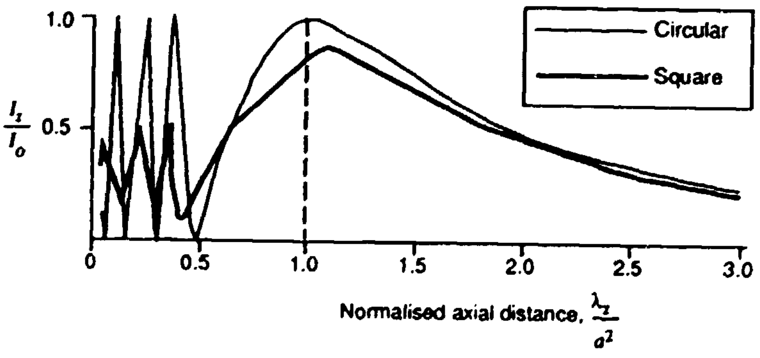


Figure 4

Radiation patterns along the central axis of a circular and square transducers. (Adapted from Wells [6])

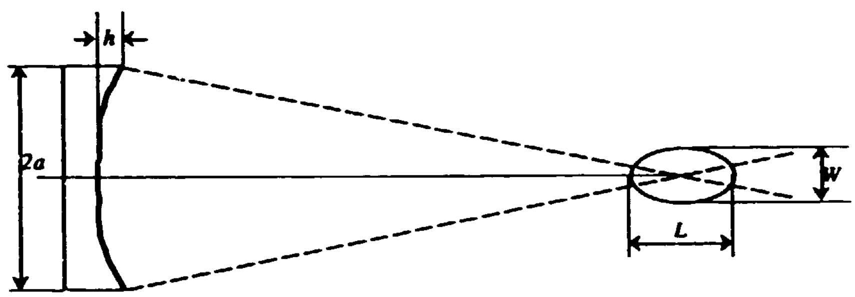


Figure 5

The effect of focusing by means of either shaping the vibrating disc or adding a lens in front of the piezoelectric material. (Adapted from Wells [6])

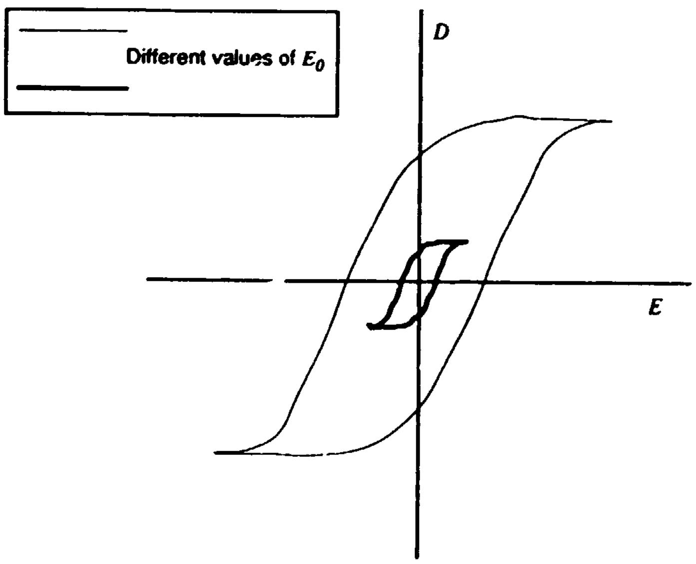


Figure 6

Ferroelectric hysteresis loops produced by two values of E_0, the maximum applied field strength.

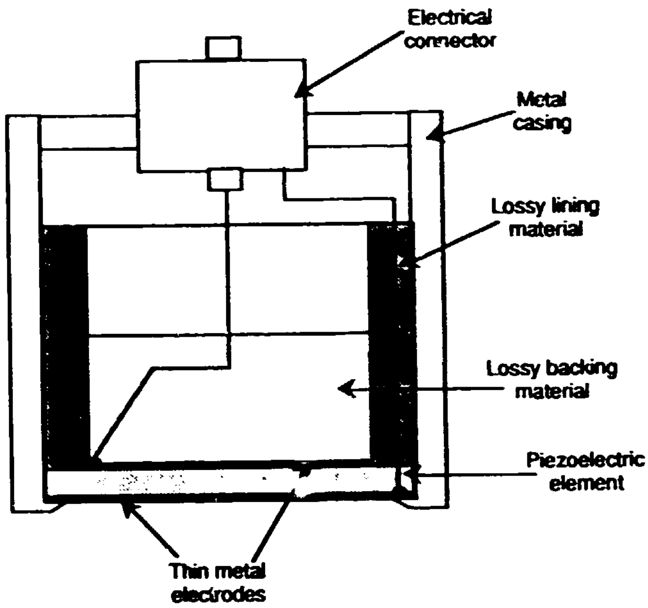


Figure 7

Construction of a simple ultrasound transducer.

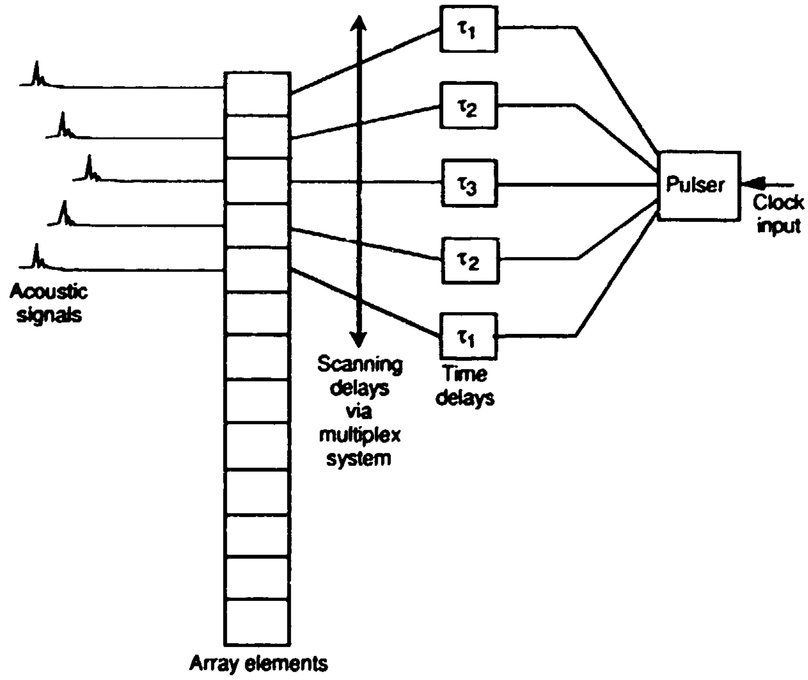
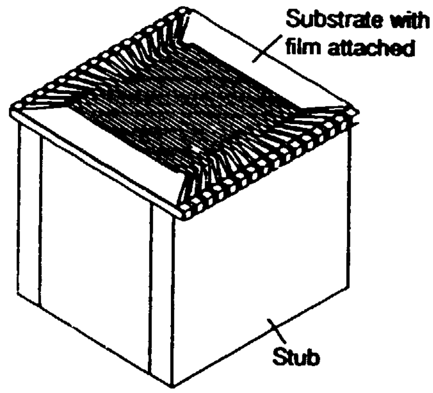


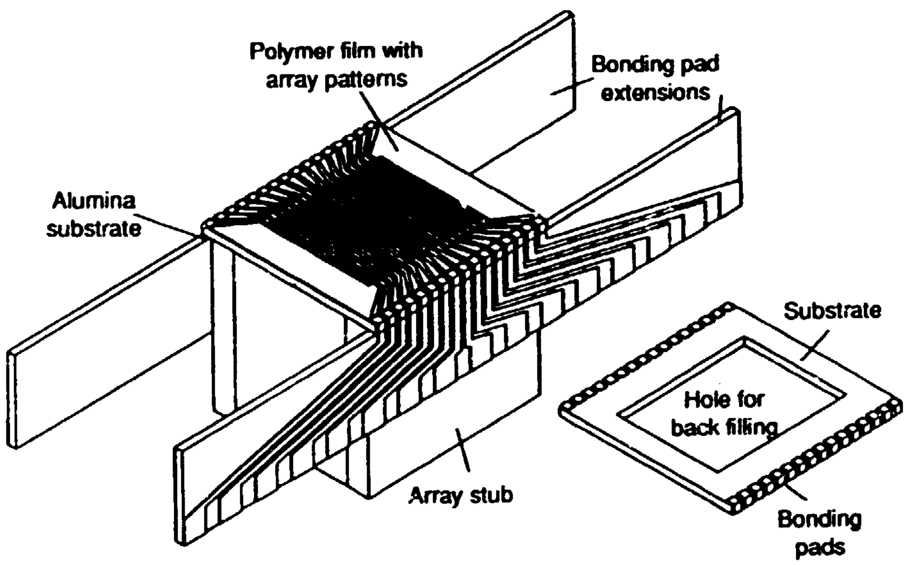
Figure 8

Outline of a linear scanning system employing multi-element ultrasound transducer array.

(a) ceramic stub and substrate assembly



(b) showing partial assembly



(b) printed circuit board layout for testing array

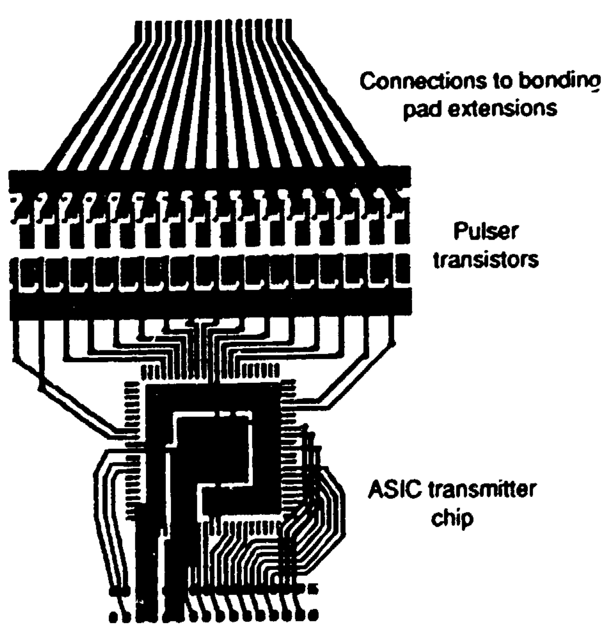


Figure 9

Constructional assembly for an integrated multi-element high frequency transducer (32 elements)

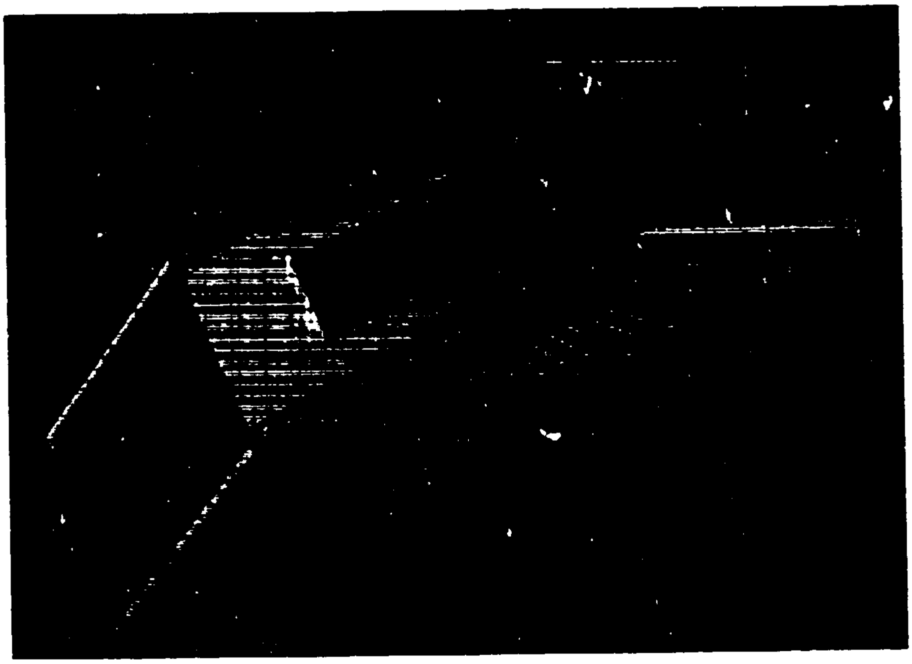


Figure 10

64-element array - partial assembly

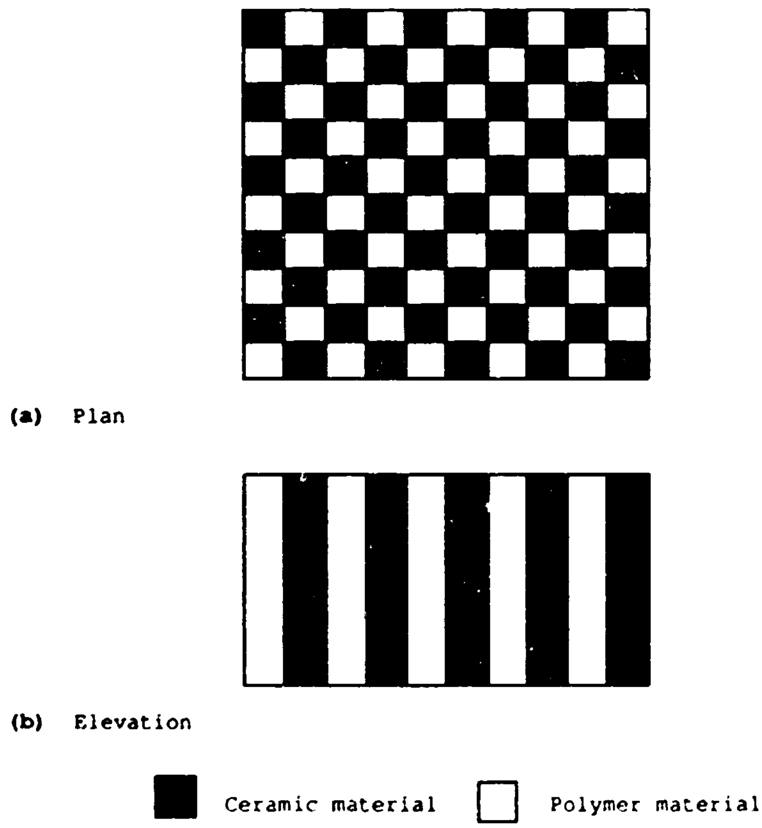


Figure 11

1:3 composite transducer element construction.

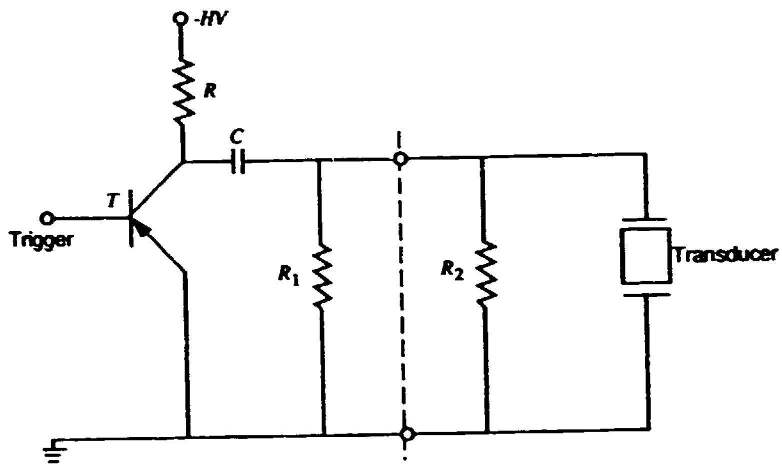


Figure 12

Simplified circuit diagram of a pulser connected to a transducer.

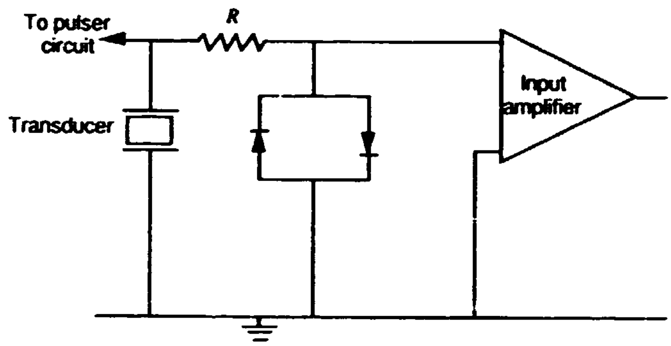


Figure 13

Back-to-back diode arrangement for amplifier protection.

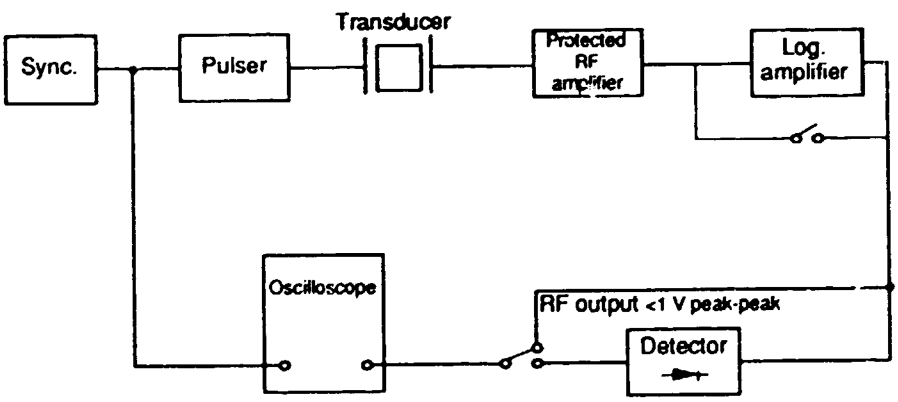


Figure 14

A simple A-scan ultrasound pulse echo system.

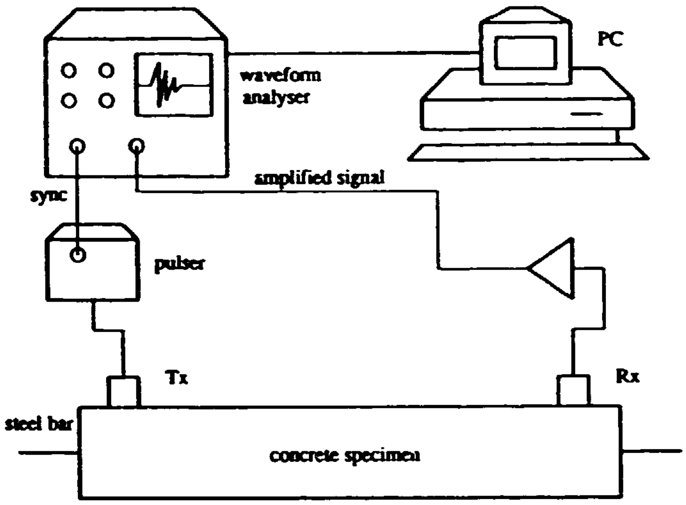
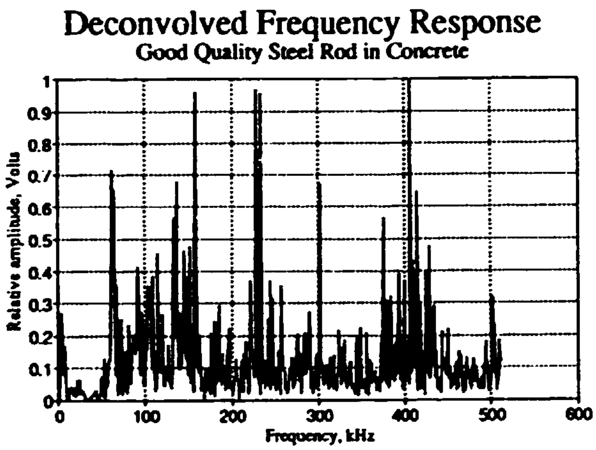


Figure 15

Experimental arrangement for the detection of the presence of corrosion on a steel bar embedded in concrete.



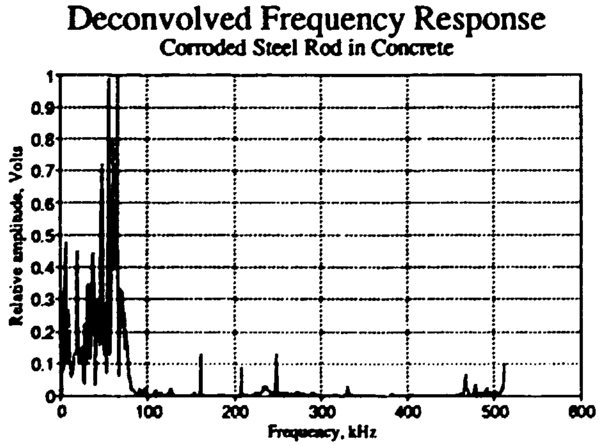


Figure 16

Frequency response results following deconvolution for a good steel rod (upper figure) and a corroded rod (lower figure)

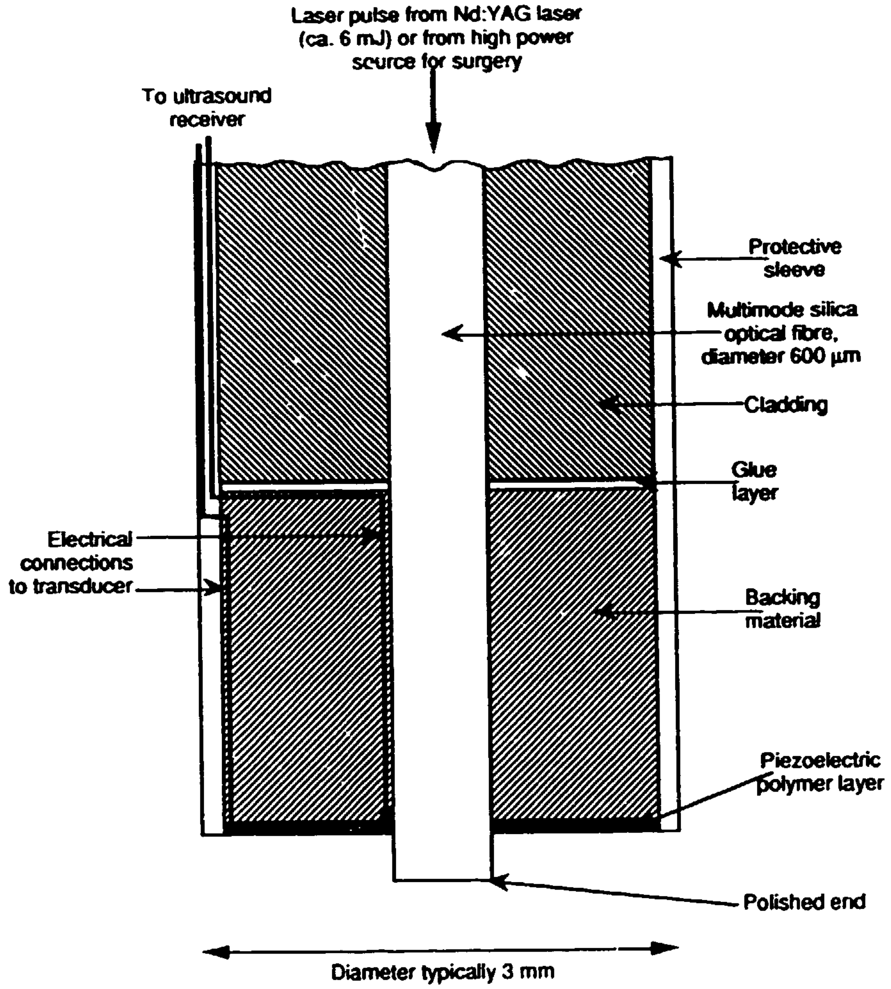


Figure 17

Combined fibre optic and polymer transducer for imaging and surgery.

2. TRENDS IN R&D

Single-chip digital image sensor/processor

An integrated circuit by the Swedish company Integrated Vision Products (IVP) combines a matrix-based image sensor (or electronic retina), an analog-to-digital (A/D) converter, and a RISC (restricted instruction set computer) processor. It can handle 1,000 binary images per second.

The image sensor developed by the Swedish firm IVP is an achievement in that it enables direct output of digital video data. The circuit, which carries the reference MAPP2200, is in fact a real digital camera on a single chip. The addition of a sequencer (in integrated or discrete components) and a lens to the MAPP2200 is sufficient to obtain a piece of equipment that can pick up an image, digitize it and sequentially transmit the digital data to an analog bus, all at a rate of up to 1,000 images per second in monochrome (1 bit per pixel) format or 150 images per second for images with 8 bits per pixel. It has little in common with the Scottish firm VLSI Vision's single-chip camera, which merely picks up an analog video signal and restores it in the form of a - still analog - composite video signal. Nor do the prices have much in common. While the Scottish "single-chip camera" sells at about $25, or FFr 140, IVP's costs Fr 9,000. The MAPP2200 is sold in France by Smart Vision, a small company founded in March 1993 by former employees of Nestor, which intends focusing on silicon-based image storage and compression systems by using its skills in the neural technologies. Smart Vision has developed a camera module based on both the MAPP2200 and neural network technology which, in a shape recognition application, can control 20 pieces per second and 255 kinds of defects.

Three independent systems for image acquisition, conversion and processing

The MAPP2200 integrates three subsystems independent of each other: the sensor, the A/D converter and the vector processor. In a digital camera application, the first two are most useful although parts of the vector processor can be used for internal and external data transfers.

The sensor consists of a 256 x 256 photodiode matrix, addressable by line of 256 photosensitive elements. This sensor uses about half the chip's surface (16.9 x 8.2 mm in 1.5-micron CMOS (complementary metal-oxide semiconductor technology)). A separate circuit is also included for protection against glare. The image data is read line by line on an output matrix and then stored in an analog input register before conversion. The conversion part consists of 256 A/D converters; actually, it includes 256 comparators and one D/A converter capable of converting an 8-bit line in 32 microseconds. The conversion part also includes a minimum of analog processing such as programming the offset of comparators to control dynamism and resolution. At the A/D converter output, the data is transferred to the vector processor via a 256-bit internal data bus. The processing part of the MAPP2200 comprises three processors: a pixel processing unit (PLU (Pixel Logic Unit)), one for processing 3 x 3 matrices used for example in filtering (NLU), and the last so-called GLU (Global Logic Unit) for processing larger matrices.

These processors also perform conventional image processing operations (improving quality, filtering, contour extraction, etc.). They can also compress the image from 0.5 to 1 bit per pixel. The MAPP2200 also has a group of eight shift registers for rapid transfer of both external and internal data and a group of general purpose registers to store intermediary results up to a maximum of 96 lines.

The MAPP2200 should directly interface with a microprocessor or a 16-bit microcontroller. It is presented in a 68 LCCC (leadless ceramic chip carrier) flat pack with glass covered window. (Source: *Electronique*, 24 June 1993)

* * * * *

Scout sensor speeds up robot laser welding

Deutsche Aerospace's Scout sensor is now able to guide a high-power laser along a curved butt-joint between sheets of glass, metal, and other materials. The development also allows the sensor to detect scribed lines.

Scout was designed to follow a lapped seam across a three-dimensional work surface with a minimum radius of curvature of 5 mm to an accuracy of approximately 0.05 mm and 0.2° to the perpendicular. An array of parallel laser lines projected onto the work surface enable the sensor to follow a seam without the need for human help. Conventional grey-scale sensors can neither identify the position of a flat workpiece nor regulate the laser focus above it.

At the moment, Scout runs over a VME (Versa Module Europe) bus but a slower version, based on a personal computer and costing DM 30,000, is expected at the end of 1993. Deutsche Aerospace, which announced the developments at the Laser 93 conference, will deliver three sensors to Volkswagen and a fourth to Merz & Cie. The deliveries will double the number of sensors installed at DM 65,000 each.

Deutsche Aerospace is a merger of long-established companies, such as MBB (Messerschmitt-

Boelkow-Blohm), Dornier, TST (Telefunken Systems Technology) and MTU (Engines and Turbines United) with many years of experience in military image processing. It was thus able to exploit accumulated know-how, particularly in the field of real-image processing to develop the sensor.

Scout consists of an evaluation unit and a 700 g sensor head - mounted directly on the robot hand and 25 mm upstream of the laser welding nozzle - which projects a line pattern from a Class 1 laser onto the workpiece. The unit checks a digitized image of the pattern, produced by an integrated camera, against a template stored in its memory, all in real time.

Since the projection and viewing directions coincide, the bars run parallel on plane workpieces and "jump" across the edge of stacked sheets. An analysis of this jump determines the distance and lateral position of the seam in relation to the robot's hand.

The core of the evaluation unit is the image-processing hardware, tailored to this special application, which consists of the monitoring and communication processor as well as parallel signal processors. Seam data passes to the robot control via a parallel or a high-speed serial interface. Standard interfaces between the sensor and the robot control are not available as yet, but the Scout computer architecture has a special feature to cope with this fact.

Scout processes a new video frame every 20 milliseconds. As it determines several points along the seam from each image, it can guide a welding beam at speeds up to 20 m min over slight curvatures. Paths with narrower radii take longer to cover. Conventional laser sensors, which scan single points on a surface, are simpler but slower because they measure sequentially.

Many seam templates can be set and stored in the Scout so that, once the robot hand is positioned at a predetermined point, the 150 x 80 x 50 mm sensor can identify its route and guide the beam. The parameters, sheet, sheet thickness, width between the sheets and orientation of the seam, for example, are controlled visually from a monitor. Scout also scans the position of the robot to orient itself and to compensate for variations in the sheet edges. The system is also suited to remote sealing and the application of adhesives. (Source: *Opto and Laser Europe*, July 1993.

* * * * *

<u>Biosensor detects formaldehyde</u>

The first-ever pocket devices for measuring the concentration of glucose (blood sugar) and lactate (lactic acid) were developed in Germany and came onto the market at the beginning of 1993, and now the breakthrough for user-friendly miniaturized biosensor devices has been made in environment monitoring as well, with the formaldehyde detector developed by Draegerwerk AG. An air pollutant detector will come onto the market in the shape of the highly sensitive "Bio-Check F" pocket meter, which is based on biomolecular detection principles. Unlike conventional metering methods, which are so complicated that they can only be applied by specialists and are laboratory-dependent, this device can be used easily, rapidly, and anywhere by anyone, and is also reasonably priced. This will encourage widespread use in the interests of improving health and environmental protection.

The main factors that had to be guaranteed in developing a reliable system that private individuals could use to measure the formaldehyde concentration in the air indoors were high sensitivity, easy use, and low production costs. An indicator surface on the "Bio-Check F" changes colour from white through pink to red, and comparison with a colour-code strip shows whether the formaldehyde concentration in the air is below the maximum recommended indoor level, is equal to it, or exceeds it. It is thus just as easy to use as, for example, an alcohol level test for drivers. The new detector also brings the cost of formaldehyde measurement way below (to less than a third of) that of the laboratory process needed to date.

Formaldehyde is widely used as a basic ingredient for synthetic resins. The gas, which in its pure form is colourless and gives off a pungent smell, is used in the production of amino plastics and phenolic plastics, which in turn are ingredients of products such as adhesives, synthetic foams, insulating materials, floor coverings and textiles (which it renders crease-resistant). If formaldehyde is released by the glues used in furniture, wall coverings and chipboard, or by furnishing fabrics, it can cause discomfort or even, in higher concentrations, constitute a health hazard. The Federal Health Authority therefore recommends 0.1 ppm (parts per million) as the threshold value for air quality assessment purposes in the home, in schools and in other indoor environments. In other words, the formaldehyde concentration ought not to exceed one-10 millionth by volume, for example 0.1 millilitre per cubic metre.

The new measuring system is enzyme-based. These biological catalysts make it possible to single out and register only the substance to be measured. To perform the measurement, the system is activated by pressing the base of a phial in the measuring device with the thumb, thus breaking it. The liquid thus released flows into a small, permeable, sintered glass rod, where it activates the freeze-dried enzymes and the reagents. Of the molecules that diffuse over the surface of the glass rod, the only ones converted are those "recognized" by the enzyme contained there (formaldehyde dehydrogenase). As a result, pigment molecules form on the surface of the rod. The colour change that takes place after two hours can be evaluated using a colour comparison strip.

Further details are available from the BEO (Biology, Energy and Ecology) Project Manager, Berlin Regional Office, Federal Ministry of Research and Technology, Hannoversche Str. 30, D-10115 Berlin, Tel.: 030-39981327, Fax.: 030 39981318. (Source: *Technologie Nachrichten, Management Informationen*, 15 October 1993)

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Bio-compatible biosensor developed

In cooperation with Nippon Suisan, Professor Isao Karube of the Research Center for Advanced Science and Technology, University of Tokyo, has developed a biocompatible biosensor that can measure glucose (grape sugar) concentrations, etc., continuously within the body for more than one month. It is made by affixing the enzymes used for the assay in chitin, which is harmless to the human body and gradually decomposes when placed inside the body. This device has potential as an implantable sensor to monitor blood glucose for use in combination with an artificial pancreas.

By giving chitin a special pretreatment, it is possible to freely adjust the time it takes to dissolve inside the body from one week to three months. To extract the results of the sugar-enzyme reaction (for glucose concentration) in the form of an electric signal, the group deposited a thin layer of gold on one side of this film and attached wires to it. Gold causes almost no damage at all when placed in the body in very small amounts.

The group created and tested a sensor 1 cm long by 1.55 mm wide. When they placed the sensor with wires attached in a solution of glucose, they could measure the concentration within 30 seconds. In future the group will study performance and safety in animal experiments, and proceed with research on methods for extracting the measurement data from the body with the goal of improving the device for practical applications, such as artificial organs.

In the past, miniature biosensors that could be placed in blood vessels have been developed, but more than half have been made of materials such as silicone. As a result, placing them in the body caused inflammation, etc., and long-term, continuous measurement was impossible. There has been great demand for biosensors that are safe when implanted in the body. (Source: *Nikkei Sangyo Shimbun*, 9 April 1993)

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Solid detection

Biotechnologists at the Cranfield Institute of Technology believe they have developed the first biosensor based on a solid, rather than a solvent, that can detect specific gases. They hope to have a working, commercial device within four to five years.

Anthony Turner, the head of Cranfield's biotechnology centre, believes that the sensor, which works independently of its environment and can operate in air, would make a good personal alarm or fixed monitor. At present, it can be tailored to detect methane, sulphur dioxide or phenol using polyphenol oxidase, sulphite oxidase and methane-oxidizing bacteria respectively.

The enzymes are enmeshed in the crystal-like matrices of an electrolytic gel, but Turner is unwilling to reveal the gel's constituents or how he makes it. He believes that by extracting most of the water, the gel forms a rigid framework. In a typical biosensor the enzymes are stabilized by a hydrophobic organic solvent, but this conflicts with the need for a hydrophilic solvent to ensure high conductivity for the electrochemistry - the method of detection - to work. By throwing away the solvents, this problem disappears, says Turner.

In all cases, the gas is oxidized by the specific enzyme or biocatalyst. Either the oxidation products or electrons from the enzyme - shuttled by a redox carrier - are observed as current at the gold electrode.

In Turner's device, two gold electrodes are held within the gel. They need to be small, so Turner uses lithography to achieve dimensions down to 7 microns. And he hopes to go even smaller. "The smaller the better and the closer together the better because it cuts down the resistance of the gel which is only poorly conductive."

According to Turner, the new biosensor which has a patent pending, will have greater selectivity than present inorganic sensors - it will not be set off accidentally by a perfume - but may not be as stable. (Source: *Chemistry and Industry*, 7 June 1993)

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Alcohol oxidase-based biosensor developed

A biosensor that in one to two minutes can measure ethanol concentrations in fermentation broths or clear filtered liquors has been developed by Yellow Springs Instrument Co., Yellow Springs, Ohio. Yellow Springs senior scientist John R. Woodward says the instrument uses immobilized alcohol oxidase to generate hydrogen peroxide from oxygen and ethanol. The hydrogen peroxide that is produced is measured at an electrode and provides an accurate measure of ethanol concentration. Woodward points out that, although gas chromatography and distillation can provide very accurate measurements of alcohol concentration, the former is relatively expensive and the latter is time consuming and requires a skilled technician. The Yellow Springs instrument is completely automated and each analysis costs between 10 and 20 cents, Woodward says. The system also can measure methanol concentrations, and this feature has been employed in a device produced to measure concentrations of the sweetener aspartame at levels found in diet soft drinks and other commercial products. This device uses chymotrypsin to cleave methanol from one of the three amino acids that make up aspartame. The alcohol oxidase generates hydrogen peroxide from the methanol and the electrode detects the generated compound. (Source: *Chemical and Engineering News*, 12 April 1993)

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Progress made in food uses of biosensors

Products of biotechnology, ranging from monoclonal antibodies to enzymes, are successfully being harnessed to develop selective, sensitive sensors for analysis of food contaminants. But despite this progress, food safety applications of biotechnology have been limited by, on one hand, resistance of food processors to new techniques and, on the other, opposition of consumers to biotechnology in general.

The application of biotechnology to food analysis has progressed in recent years, but acceptance of the new techniques has lagged behind their development.

Biotechnology-based diagnostics exist or are being developed for analysing contaminants at every stage of the process of bringing food to market. Although traditional analytical chemistry and microbiological techniques have met the needs for food analysis, the methods are limited by complexity, time required for analysis, and cost.

Scientists are using biotechnology to address these limitations. Immunoassays have been developed for a variety of food components and contaminants including amino acids, sugars, alcohols, pesticides, and organic compounds. Nucleic acid probes focus on identifying pathogenic micro-organisms in food. And biosensors are being developed to detect food components and contaminants, as well as to determine quality variables such as odour and taste. (Extracted from *Chemical and Engineering News*, 19 April 1993, p. 37)

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Sensor observes cell metabolism in tissue culture in real time

A newly-developed electrical sensor will continuously monitor how cells behave without taking them out of the incubator, without touching them, and without requiring long hours bent over a microscope.

The sensor will tell researchers when minute disturbances in cells indicate potential trouble in a biomolecule production process.

Charles R. Keese, formerly senior research scientist at Rensselaer Polytechnic Institute, and Ivar Giaever, Professor of Physics at RPI, a 1974 Nobel Prize-winner in physics, have demonstrated how their ECIS (electric cell-substrate impedance sensor) can also track changes in the cell when biological or chemical substances are added. The essential component of the sensor is a tiny (less than .001 square centimetres) gold electrode in a tissue culture dish. A very low (1 microamp) alternating current is passed through the culture medium.

The medium carries the current, while the electrode on which the living cells are cultured act as insulators. Changes in cell morphology, however slight, produce changes in the electrodes' impedance.

The sensor's computer continuously observes and records the impedance changes in real time. Only about 100 cells can populate the small electrode, but the activity of even a single cell can be detected. ECIS can observe the metabolism of almost all types of cells so long as they can anchor to surfaces in culture - a property of most animal cells, the inventors declared.

A prototype ECIS is now in a feasibility test at the Johns Hopkins Cancer Research Center, where studies had confirmed a close correlation between cellular metabolism and metastases. Preliminary results show the sensor is quickly and reliably predicting tumours most likely to metastasize. Giaever and Keese recently formed Applied Biophysics Inc., based at Incubator Center, Rensselaer Polytechnic Institute, Troy, NY, to produce the sensor commercially in 1994. (Source: *McGraw Hill's Biotechnology Newswatch*, 16 August 1993)

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FAIR-FLOW notes

Biosensors for detecting bacteria

A European Union FLAIR shared-cost project with four partners is ongoing on the development of an acoustic biosensor to detect food spoilage and/or pathogenic bacteria. For more information contact Professor F. O'Gara, Department of Food Microbiology, University College, Cork, Ireland. Tel.: (021) 276871; Fax: (021) 275934.

Sensors for sanitation

A range of sensors is being developed that will prove invaluable for detecting levels of fouling in the inaccessible parts of food processing equipment. For more information on this FLAIR shared-cost project contact Dr. H. O. Mikkelsen, Biotechnological Institute, Holbergsvej 10, PO Box 810, DK-6000 Kolding, Denmark. Tel.: +45 75 52 04 33; Fax: 45 75 52 99 89. (Source: *Irish Biotech News*, January 1994)

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Novel sensor development for effluent

BTTG Research and Technology is seeking industrial support to help develop a novel biotechnology sensor capable of detecting low concentrations of metal ions in effluent.

Scientists at the group's Shirley Technology Centre in Manchester, United Kingdom, believe their concept - based on fungal bioabsorption of metal ions - holds promise to distinguish between species of metal ion and detect each quantitatively.

In this respect, the new sensor would theoretically have advantages over ion-selective electrodes, which tend to be slow and dedicated to one single metal ion.

According to David Wales, head of BTTG's biotechnology section, the binding of metals should alter the conductivity, permittivity and mass of microfungal material. Any means of detecting a change in one of these parameters would hold potential as a sensor.

BTTG scientists claim to have already demonstrated that microfungal filaments will effectively bind a variety of metals in solution.

Wales expects the project to be of two to three years' duration, in which time it should be possible to devise the methodology of the sensor.

Funding from the United Kingdom Government's Department of Trade and Industry under the LINK initiative is also being applied for.

The group believes the sensor should be of interest to industry and the water authorities alike.

The project is being conducted in conjunction with Queen's University, Belfast, which is providing the electronics expertise for the sensor development.

Separately, BTTG is also seeking funding from HM Inspectorate of Pollution to scale-up a related technique - to use the fungal bioabsorption concept to remove metal ions.

Funding would allow the project to advance from the laboratory to the pilot stage. (Source: *European Chemical News*, 21 February 1994)

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Molecular recognition

Scientists at the Naval Research Laboratory (NRL) in Washington believe they are the first to measure and study directly a single molecular recognition interaction. The technique, which uses an atomic force microscope (AFM), has potential for use as a chemical/biological sensor or as a cell mapping device.

Molecular recognition is the basis for assembly and regulation in living organisms. But characterizing discrete interactions can be difficult because of the very small forces and distances involved. However, it is in this area that the AFM shines. As Richard Colton of the NRL explains, the AFM is sensitive to forces of 10^{-14}N and to displacements of 0.01 nm; can control contact areas as small as 10 nm^2; and can work on living systems as well as on synthetic ones.

The NRL team, including Gil Lee and David Kidwell, measured the adhesive forces between the receptor streptavidin and its ligand, biotin. By attaching biotin to the surface of a sphere at the end of a cantilever beam, and attaching streptavidin to another surface, the interaction force between the two species can be measured by approaching, and then retracting, the two surfaces. Using this method, the team say they have measured adhesive forces three to eight times greater than normal "background" forces. These forces, they believe, result from the rupture of one biotin-streptavidin bond.

As the biotin and streptavidin molecules are constrained sterically, and the location of the binding site is buried deep within the streptavidin molecule, the number of possible interactions is greatly reduced. This, and the magnitude and distribution of the observed forces, implies that the rupture force of a single molecular recognition event has been measured, they claim.

"This work shows that the AFM can be used to measure a molecular recognition interaction while controlling the surface properties, area of contact and environmental conditions", Colton says.

Colton hopes to have a laboratory prototype of a chemical sensor within two years. As well as applications in medical diagnostics, it may also have environmental use - detecting pesticide residues, for example. But it could also be used to map the surface of a cellular membrane so that binding sites can be pinpointed and studied one at a time. (Source: *Chemistry and Industry*, 4 October 1993)

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Standards institute sets up advanced biosensor consortium

To meet the challenges of designing biosensors that are accurate, reliable and easy to assemble, the National Institute of Standards and Technology has started the Consortium on Advanced Biosensors (CAB) The purpose of the consortium is to support research aimed at solving problems that prevent commercialization of biosensor technologies. The initial corporate members of CAB are Becton Dickinson Advanced Diagnostics, Ciba-Corning Diagnostics, Dow Chemical, Du Pont Medical Products, Miles Inc. and Ohmicron Corp. EPA has joined the consortium as an interagency partner. In CAB's first research project, scientists will focus on minimizing background interference from biosensor signals and the binding of charged proteins to different chemical surfaces. Consortium members will select future projects and support them through annual membership fees of $15,000 or $30,000, depending on company size. Members are entitled to exclusive licences on patents granted to technologies developed through the consortium. More information is available from Howard Weetall, NIST, A353 Chemistry Building, Gaithersburg, MD 20899-0001. Tel.: (301) 975-2628. (Source: *Chemical and Engineering News*, 26 July 1993)

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Analysing structural/functional biomolecular interactions via biosensors

While a great deal of knowledge has been accumulated on the structure of various molecules, and even on some of the more important functions, little seems to be known about the relationships that exist between molecular structure and biological function or the molecular functions that are fulfilled through the interactions of molecules.

Most researchers agree that these interactions can best be described in terms of molecular affinity, association and dissociation rates and the stoichiometry with which molecular complexes are formed. To adequately study these parameters, more powerful analytical techniques have been needed.

Commercial instruments are now in use that combine specially constructed biosensors and novel optical detection technologies for real-time characterization of molecular interactions. However, with price tags over $75,000, their use has been limited to research laboratories within the pharmaceutical industry and the better-financed research institutions. Here, they are being used in drug design, vaccine development, nucleic acid research, antibody characterization and the study of cell adhesion and signal transduction. Their most common use has been for the kinetic analysis of monoclonal antibody and recombinant antigen interactions. Qualitative and quantitative information on isotype, epitope specificity, affinity, kinetics and immunoreactivity can be readily obtained. In addition, numerous papers have been written on their use in the functional characterization of protein-protein, protein-DNA, and ligand-receptor interactions.

Applications have been growing rapidly, mainly directed at the study of biomolecular recognition, binding patterns, mapping or multi-molecular interactions and the kinetics of molecular association and dissociation.

All biosensors combine biological and electronic components to convert a biological event into an electrical signal that can be further processed and displayed. The biological component, sometimes referred to as a biolayer, typically involves an antibody, receptor, nucleic acid, protein, enzyme, micro-organism or even tissue. The biological event involves the association, or binding, of an analyte with the biolayer. In most cases, this event is then detected as a change in biolayer charge, thickness, refractive index, viscosity, and/or mass by an electrochemical or optical detection device.

Biosensors are usually constructed with a thin layer (approx. 100 nm) of a high molecular weight carboxymethyl dextran covalently attached to their surfaces. The purpose of the dextran layer is to provide a hydrophilic matrix for immobilization of the ligand that will bind the analyte.

To conduct an assay, one of the molecules in the binding pair of interest is immobilized to the sensor surface. Using a wide range of chemistries, amino, thiol or aldehyde groups on the molecule are bound to the carboxyl groups in the dextran matrix. Alternatively, a capture system can be used, such as anti-species antibody or streptavidin-biotin chemistry.

Then the sample is brought into contact with the biolayer and the association process is monitored until equilibrium is reached. To measure dissociation, the sample is replaced by an appropriate buffer.

For the analysis of analytes smaller than 5,000 daltons, indirect techniques are used. The analyte is mixed with a known amount of a high molecular weight binding molecule. Then the technique is used to assay for the binding molecule that remains unbound. the fluid-handling portions of the systems have been designed so that macromolecules, large particles, vesicles and whole cells can also be analysed.

The optical detection technologies used in these instruments rely on an "evanescent field" that is created in the sample within a few hundred nanometers of the biosensor surface. This evanescent field is the electromagnetic component of light that is generated when it is totally reflected at the boundary of two materials with dissimilar refractive indexes.

By detecting changes in the evanescent field, the instrument can measure the change in mass near the surface of the biosensor as analyte is either bound or dissociated. Since the evanescent field only extends a short distance into the sample, the response of the instrument is unaffected by events occurring in the bulk of the sample.

Basically, there are two technologies used in commercial optical evanescent detectors. These are surface plasmon resonance (SPR) and a technique called "waveguiding". A third detection technique, called resonant mirror technology, combines features of SPR with those of the more classical waveguiding technique.

The cost of the consumable biosensors is still quite high because of the small volumes that are typically manufactured in a production run, and the manual processing steps that are employed. Biosensor reuse is also limited by their inherent degradability and the fouling that occurs from their direct contact with the sample.

Biosensor costs are expected to remain high until more advanced manufacturing techniques, such as those used in the integrated circuit industry, are adapted for use. (Extracted from *Genetic Engineering News*, 15 February 1994)

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Fibre optic sensors

The concept of combining optical fibre technology with environmental sensing to create a fibre optic sensor has been with us for over 20 years. It is not difficult to understand their appeal: they are reliable, simple and have no moving parts; they can be more sensitive than mechanical or semiconductor sensors and are immune to electromagnetic interference. They can offer high bandwidth and, being inherently safe, may be installed in hazardous areas, eliminating the need for safety barriers.

In a fibre optic sensor, light from a source is guided down a fibre to a point where the measurement is to take place. At this point the light may leave the fibre and be modulated in a separate region by the measurand. The signal is then relaunched into the same or a different fibre. These are known as extrinsic sensors. Sensors in which the light is modified by the measurand whilst guided in the fibre are known as intrinsic. In both groups the returning light is converted to an electrical signal to provide the measurement output.

There are several parameters associated with a light beam which may be used as the basis of a fibre optic sensor. They are intensity, phase, spectral content and state of polarization. They may be modulated in both intrinsic and extrinsic sensing configurations. By modulating one or more of these parameters, it is possible to construct optical sensors for the measurement of a wide range of measurands.

For instance, in one intrinsic sensor, by applying pressure to the optical fibre the intensity of the light may be reduced due to micro-bending. By measuring the ratio of the light received back from the sensor to the light transmitted, very small movements may be translated into large attenuations, making the sensor extremely sensitive. Applications range from contact sensing bumpers, sensing barriers around dangerous machinery to the structural monitoring of bridges. Some extrinsic sensors use specially manufactured fibres that react by changing their spectral attenuation in response to their environment and may be used to detect the presence and measure the concentration of chemical signals.

Inherently distributed

In the micro-bending example the optical fibre may be many tens of metres long but measuring only the light intensity will not indicate the location where the pressure is being applied. In conventional sensing - where multiple points of information are needed - the individual sensors are distributed among the points of interest and multiplexed through the data acquisition electronics. The optical fibre equivalent is more advantageous because it is inherently distributed and therefore can monitor multiple points without knowing the optimum position for discrete sensors.

In order to provide the positional information a key technique employed in optical fibre distributed sensing is optical time domain reflectometry or OTDR. This is an established method in the telecommunications industry for checking the integrity of optical fibre cable installations. A pulsed laser source launches through a directional coupler into the fibre. As the pulse passes down the fibre, properties of the fibre core cause the light to scatter in all directions. A proportion of this scattered light is retained in the core and guided back towards the source. The fibre in this case acts not only as the transmission medium but also as an intrinsic sensor.

In a uniform fibre, the intensity of this returned light shows an exponential decay with time. Therefore, knowing the speed of light in fibre and the distance that the light has travelled down the fibre, variations in the properties of the fibre show up as deviations from a perfect exponential decay of intensity with distance.

Effects take place when the light interacts with the glass core. In fact the spectrum of the returning light has properties which may inform us about measurands acting on the fibre. Temperature and strain can both be measured this way. By processing backscatter wave forms the true spatial distribution of the measurand can be obtained for the whole length of the sensing fibre.

Distributed temperature sensing (DTS) is an intrinsic sensing technology. The sensor can typically perform many thousands of measurements at intervals of 1 m over several kilometres in seconds. It is used, for instance, in the power industry to monitor the temperature profile of a power cable in order to detect hot spots and predict cable loads. The volume, accuracy and frequency of data has opened up a number of opportunities in the process industries.

The sensor is an inexpensive and widely available optical fibre of the type commonly used in optical communications. The "black box" is comparatively expensive and so use is made of optical switching techniques in order to have many sensors shared among the data acquisition and processing hardware. This allows for redundancy and increased performance. Using this configuration, the temperature can be measured to one in 40,000 with a single instrument.

Measurement loop

The DTS system manufactured by York Sensors uniquely not only uses such a switching device for increasing the number of sensing fibres but also to switch between both ends of the fibre creating a measurement loop. By doing this, loss effects in the fibre are eliminated and allow typical accuracies in temperature measurement of ±0.3° C. Additionally, measurements may continue even if the fibre sensor detects a break.

The most active application area for this new sensor technology is in the power supply industry where the long length of energy cable used, together with the inherent rejection of the EMI makes it an ideal candidate for the monitoring of power cables. Trials were undertaken as early as 1989 and cable systems are now being installed with optical fibre monitoring designed into the cable from inception.

In some cases the optical fibre cable is installed into the cable structure and in others laid alongside the cable in the same trench. In either case, the operators are gaining information as to the peak transmission capacity of their transmission line and they are able to regulate their load taking into account the current, actual load capacity (which might vary with ground conditions and temperature, cable location, routing and dissipation of other nearby services) rather than its design load.

Trials have taken place in the application of the technology to the gas supply industry including the monitoring of process plant and the detection of leaks in large LNG installations. The coverage offered by such an instrument, together with the absence of explosion hazards, have given the technology a strong advantage in these fields.

DTS is also being successfully applied to niche markets in the chemical process industry. Manufacturing processes usually take place in hostile, unfriendly environments such as pressure vessels, brick-lined reactors, ovens and driers. A hot spot can suddenly occur in an unpredictable location when for example a failure occurs in a refractory lining.

Optical fibre laid as a sensing mesh on the surface of a vessel can scan the profile and isolate hot spots as small as 300 mm among changing temperature patterns. In an application of this sort 3,000 to 4,000 thermocouples with associated wiring and periodic calibration would be required to provide the same level of monitoring.

Added to that the constraint of hazardous area and intrinsic safety regulations and the formula of a single, low power distributed sensor with one calibration point, coupled with the advantages of optical data transmission, is hard to beat.

The general use of fibre optic sensors in the process industries is no doubt growing as conventional sensors are replaced with fibre optics and conventional sensor companies acquire fibre optic sensor technology. Temperature, pressure, chemical analysis, flow and liquid level are just some of the sensing measurands that are performing useful roles. The advantages perceived by the industry are high integrity, lower maintenance costs and reliability.

So far user conservatism has meant that the take-up of this technology and the subsequent replacement of conventional transducers with optical fibre sensors is slow. The experience that has now been gained in the successful application of DTS in solving specialized monitoring problems in the process industry may well assist in securing the future acceptance of optical fibre sensors.

The growth of optical fibres for data transmission in the process industries will initially outstrip that of fibre optic sensors except in niche applications and where discrete sensors offer price/performance advantages. (Source: *Engineering*, December 1933)

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Sensors: sense and comprehension

Intelligent systems revolutionize automotive, environmental and medical engineering

With the aid of micro-electronics, sensor technology has been thrust into an entirely new dimension. Today, tiny sensors can already touch, taste, see and hear. They measure position, pressure, angular speed and humidity, or aid in the analysis of chemical concentrations. These midgets, moreover, are much cheaper than conventional measuring sensors. While a conventional sensor recording the electrical conductivity of liquids costs about DM 400, its micro-electronic descendant can already be purchased for DM 10.

This rapid price reduction has been made possible by known silicon processing techniques. Just as in the production of micro-electronic chips, several hundreds of sensors can be simultaneously mounted on one wafer - a disk the size of a beer cap.

The most advances in microsensor engineering have been made in the automobile industry. In the mid-1970s, Mercedes-Benz and BMW began making the automobile more "intelligent" by using sensors. The antilock braking system, electronic transmission control and air bags would not be conceivable without microsensors. For their de luxe cars, Mercedes-Benz and BMW have advanced the development of sympathetic shock absorbing systems to the extent that they are ready for the production line. Aided by a small acceleration sensor, the computer in the vehicle recognizes road conditions as well as the operating mode and then, within milliseconds, adjusts the drive characteristic accordingly.

This is only the beginning. Automobile developers envision a rainfall sensor to control the speed of windshield wipers. When a child suddenly appears on the road, electronic micro-optics will respond faster than the driver. Soon a mini-radar may take over navigation through fog.

Whether in vehicle design, process control or environmental and medical engineering, the demand for bargain measuring sensors is increasing by leaps and bounds. While the total market volume of sensors world-wide already amounted to DM 30.6 billion in 1990, projections by the VDI/VDE Technology Centre for Information Engineering Ltd. in Teltow near Berlin (VDI: Verein Deutscher Ingenieure = Society of German Engineers, VDE: Verein Deutscher Elektrotechniker = Society of German Electrical Engineers) indicate an increase to DM 65.1 billion by the year 2000.

This growth is attributable most of all to microsensors. Their share, *ad valorem*, will climb from DM 10.2 billion to DM 43.4 billion. Whole armies of measuring "fleas" will conquer all areas of engineered life activities.

So far the German sensor manufacturers hold a good position in this dynamic field. A new assistance programme has been unveiled by the BMFT (Federal Ministry of Research and Technology) offering financial support, above all to small innovation-minded enterprises.

Innovations in microsensors are still advanced mostly by the large manufacturing firms, above all by Bosch, by both DASA and AEG (General Electric Corporation) subsidiaries of Daimler-Benz, and by Siemens. The project developers are already working on second-generation sensors, which will combine perception and comprehension, with sensors and signal processors integrated on one chip. Simultaneous fabrication of sensors and electronics is still in the experimental stage.

Temic Telefunken Microelectronics Ltd. a joint enterprise of both Daimler-Benz subsidiaries AEG and DASA, established for consolidation of all microsystem activities of the parent corporation, is constructing its own manufacturing facility in its Swabian Nabern plant. Two years from now intelligent sensors, especially acceleration sensors, are to be produced in quantities up to millions of units.

The function they perform is based on the fundamental law pertaining to the moment of inertia of a body. On a silicon chip is etched out an almost entirely separate tiny square wafer, which only three thin and narrow bridges connect to the remaining part of the structure. The position of this wafer changes during acceleration and braking. Those thin bridges then bend so that their electrical resistance changes. The electronics compute that resistance and, when necessary, release the air bag.

In this way such a microsensor will in future vehicle models replace the present three-to-five conventional accelerometers, with the additional advantage that it tests itself every time the engine is started.

Mannesmann Kienzle Ltd. in Villingen-Schwenningen is already installing such sensors in one mass-produced device: an accident-data recorder used for retaining the circumstances of an accident. Innocent drivers can thus be readily exonerated, while drivers at fault need not be afraid of the others testifying as key witnesses. So long as it is not legally mandated, they may refuse to surrender their cassettes with relevant data. (Excerpts from *Wirtschaftswoche*, No. 44, 29 October 1993)

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<u>High resolution smart image sensor with integrated parallel analog processing for multiresolution edge extraction</u>

Abstract

A recent paper presents a vision sensor that generates a multiresolution edge description using parallel analog processing support. Its multimodule architecture is based on a Multi-port Access of photo-Receptor (MAR) hexagonal sensor coupled to an external but powerful analog processing unit and a microcoded digital interface. The system supports image scanning and edge tracking. Satellite analog processing allows extensive computation using VLSI technology, leaving all the sensor area available for photo-

transduction and communication pathways. It is thus possible to design a sensor with up to 500 x 500 pixels on a single CMOS chip using 1.2 µm technology. The goal of the approach described here is to exploit an imbedded edge-tracing algorithm in order to generate a scene description as a list of connected edge segments. Experimental results are presented for the current prototype which implements 256 x 256 pixels with corresponding multiresolution edge maps.

A new concept for a focal plane processing sensor has been presented and is designed to link acquisition with tightly integrated satellite processing. The prototype implements Marr's theory based on the convolution of an image with circularly symmetric operators followed by zero-crossing edge detection. It defines the sensor with reasonable resolution and multiresolution edge extraction capabilities, within a compact package and with flexible and high-performance operating modes. The feasibility of a sensor with a resolution up to 500 x 500 pixels is an important consequence of this concept. The integration of the microcoded controller, analog processing units as well as the operating software that will support intelligent and automatic feature extraction is being carried out. Ongoing work includes the development of post-processing VLSI modules for scale-space integration, stereo matching with two MAR sensors and shape-from-shading. It is believed that the early and medium processing capabilities of the architecture discussed here could contribute to the development of economical and efficient implementations of intelligent sensing devices capable of generating a compact scene description for subsequent segmentation processes. (Source: *Robotics and Autonomous Systems* 11 (1993), Elsevier. Article written by: Marc Tremblay, Denis Laurendeau, Denis Poussart, Laval University, Computer Vision & Digital Systems Laboratory, Dept. of Electrical Engineering, Ste-Foy, Quebec, Canada G1K 7P4)

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Multisensory shared autonomy and tele-sensor programming - Key issues in space robotics

Abstract

The long-term goal of our robotics activities has always been based on the idea of relieving man from inhuman and dangerous tasks. While in the early years of robotics the main focus of interest was restricted to designing robot sensors (and sensor-based man-machine interfaces) and closing smart sensory feedback loops, in recent years the activities have widened considerably. Presently, the general goal is the design of a new generation of multisensory lightweight robots for space applications, which are operable by astronauts as well as from ground stations, based on powerful telerobotic concepts and man-machine interfaces. This goal is characterized by a high degree of interdisciplinarity and consists of a few major task areas, such as mechatronics (sensory and actuator developments), telerobotics (remote control concepts for space robots), and learning (and self-improvement).

In the early years of robotic activities, cooperation with terrestrial industry was predominant. However, the last five years were characterized by close cooperation and contracts with space industry. The space robot technology experiment ROTEX - Europe's first active step into space robotics - was massively based on the concepts and systems developed here (multisensory gripper, local autonomy, telerobotic station); nevertheless in the future there will be considerable effort to transfer technology developed for space (e.g. light-weight concepts) back to terrestrial applications. (Source: *Robotics and Autonomous Systems* 11 (1993), Elsevier. Article written by G. Hirzinger, DLR (German Aerospace Research Establishment), Oberpfaffenhofen, D-82234 Wessling, Germany)

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Researchers develop gallium arsenide infrared sensors

Today's largely perfected gallium arsenide technology, according to more recent development work by Israeli physicists at Hebrew University in Jerusalem, makes it possible to make more efficient and less expensive imaging infrared sensor systems than those based on mercury - cadmium telluride. A large number of infrared sensors can be produced in the form of complete arrays on a chip by means of this process.

The signal-processing circuits can also be accommodated on the same chip. The circuits produced in the laboratory operate in the middle infrared region of the spectrum between wavelengths of 8 to 14 micrometers.

In spite of excellent images, the sensors used up to now had several shortcomings, such as relatively long signal-processing times, poor image contrast, great temperature dependence and high sensitivity to mechanical influences. High production costs, including mechanical protection of these sensors, had to be accepted in order to offset these shortcomings. The experimentally-produced gallium arsenide detectors bring about high image quality because they are designed with "quantum-well" (QWIR) structures. Here it is a question of well-like layered structures that keep electrons "locked up" so their energy can be used.

Experience in the construction of semiconductor lasers, modulators or so-called PIN diodes (semiconductor diodes), in which this quantum effect is also utilized, can be adopted in the production of gallium arsenide detectors.

The experimental type available today uses an advanced basic structure of QWIRs produced both by molecular-beam epitaxy and by metal-organic chemical vapour deposition (MOCVD) processes. The detector structures measure 50 by 50 micrometers and are based on the standardized two-micrometer raster structure.

Test measurements have shown that the sensors can be operated with very strong amplifiers, display very low reactive current and have very fast reaction times. In order to achieve the best possible imaging, it is possible to operate in the temperature range of higher than 80 kelvins (50 kelvins for mercury - cadmium telluride). The cooling effort required can thus be kept lower.

In the near future it is planned to construct a sensor on a single chip, with 256 by 256 detectors in the form of an array, together with the signal-processing circuit. Comparisons will be able to be made between this and the conventional infrared systems.

Apart from military purposes such as target acquisition and reconnaissance, the new systems can be used for example for non-invasive diagnosis of cancer, checking building insulation, infrared images, monitoring large electrical plants, or in environmental protection, detecting large-area fires from satellites, according to reports from the Hebrew University of Jerusalem (School of Applied Science and Technology, Division of Physics, Jerusalem 91042, Israel). (Source: *Frankfurter Zeitung / Blick durch die Wirtschaft*, 31 March 1993)

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3. APPLICATIONS

Sensors for (almost) every application

Sensors are indispensable to industrial applications, where they measure parameters such as pressure, temperature, flow rate, rotational speed and direction of movement as well as current and power. At the "Sensor '93 exhibition" in Nuremberg, the Semiconductor Group and Siemens Matsushita Components presented a wide range of sensors for virtually every application. In thermistors, the spotlight was on customized NTC thermistors from Siemens Matsushita. These can be supplied in packages of metal, glass or plastic, encapsulated in epoxy resin, or as plastic injection mouldings. Sockets and terminals can also be customized. Highlights of the ferrites on show were large-volume pot cores and single cores as required for proximity switches and contactless power transmission. One innovative product that made its debut was a ferrite polymer composite material (FPC) with a plastic additive. This is distinguished from pure ferrite by its close tolerances (less than 0.5 per cent shrinkage), wide frequency spectrum and low losses.

Semiconductor sensor displays focused on low-cost Hall-effect switches for the mass market, such as the TLE 4935 for position detection in gearboxes. For special applications, the Semiconductor Group presented absolute pressure sensors, which can display pressures from several hundred millibars up to 200 bar. The sensor function is based on the piezoelectric effect. A built-in reference vacuum for the test pressure makes it possible to measure the absolute pressure. (Source: *Siemens Components* 5/93, Vol. XXVIII, November 1993)

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Infrared sensors

Designed to provide total reliability in tough industrial environments, Telco infrared sensors are unaffected by water, steam, dust, dirt, vibration, high temperature or sunlight.

Unit size is 10 x 40 mm. The sensors may be used in through-beam, proximity or retro-reflective modes, operating at a distance of up to 35 m when working with a PA amplifier. Flexible transmitter and receiver construction makes mounting easy. (Source: *iti, International Technology & Innovation*, Vol. 30, No. 2, March/April 1993)

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Making sensors of bearings

By incorporating a sensor into a standard deep groove ball bearing, SKF has developed a device that could hugely simplify monitoring tasks.

With no need to modify shaft or housing diameters, the rotational measurement function can be included at the design stage without additional sensor arrangements. With suitable signal processing added, the system can measure angles, speed, acceleration and direction of movement as well as the number of revolutions.

Any integral seal/shield can be fitted on the side of the bearing opposite the sensor, while the sensor side is protected by a special labyrinth arrangement.

The only dimension of the unit affected by the sensor assembly is the width of the housing. The applications must be endless. (Source: *iti, International Technology & Innovation*, Vol. 30, No. 2, March/April 1993)

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Selective UV sensor in a hermetically sealed T05 housing

The ultraviolet sensor UVS1 contains a compact combination of a UV-sensitive Photodiode with an additional colour glass filter and an amplifier circuit.

These three components are hermetically encapsulated in a lenscaped T05 housing, to provide high immunity from electromagnetic interferences and humidity. Peak sensitivity is at 310 nm with a half width of approximately 120 nm. The sensor provides an accurate, high-level analog output signal proportional to the intensity of the ultraviolet light.

Absolute responsivity is typically greater than 100 mV per nW at the wavelength of 310 nm and a supply voltage of +5 V. The ration of the responsivity at 300 and 700 nm is greater than 10,000.

Typical applications include flame detection, laser light detection, chemical and biomedical analysis and environmental control. (Source: *iti, International Technology & Innovation*, Vol. 30, No. 2, March/April 1993)

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Liquid sensor assures sample volume repeatability

An innovative, non-contact liquid sensor, this unit assures highly accurate, sample volume repeatability in streamline 800 SL samplers.

Detecting the presence of liquid at the sampler's pump inlet, the non-contact liquid sensor adjusts pumping time to assure sample volume repeatability regardless of changes in lift.

Should the intake become plugged, the sampler initiates a high pressure purge and repeats the collection attempt. Helping to eliminate cross-contamination, the sensor facilitates pre-rinsing of the intake line prior to sample collection.

The sensor further detects the absence of line liquid, alerting the sampler's microprocessor to the condition, initiating logging and retry activity.

Sensor operation is unaffected by line coating, film build-up, water composition, temperature, viscosity, or waste stream conductivity. (Source: *iti, International Technology & Innovation*, Vol. 30, No. 2, March/April 1993)

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Honeywell's making sense of the sensors

There is news of a new temperature-compensated Hall-effect magnetic position sensor from Honeywell.

Called the SS400 Series, the units are going to find applications typically on brushless motors in automotive and harsh industrial applications, door interlock sensing, rpm measurement, flow-rate detection, piston detection and other position sensing applications.

An upgrade of the SS4 Series, the new sensor has a flexible building-block arrangement making it quick and easy to modify the magnetics to suit customer requirements, while the sensor's small size (4 x 3 x 1.6 mm) allows it to be used in tight spaces.

Sensors in the range maintain desirable and predictable magnetic characteristics over a wide temperature range and can be used reliably with low-cost magnets. (Source: *iti, International Technology & Innovation*. Vol. 30, No. 2, March/April 1993)

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Selective UV sensor suits flame detection and general sensing

Employing a photodiode, filtering system and integral amplifying circuitry for reliable and accurate flame detection, the OS1310 is designed with a narrow band response tailored to exactly match the 310 nm light emission peak in combustion flame.

Performance surpasses selenium and photo transistor detectors. In addition to flame detection, the device is suitable for use in a wide range of low signal level and general sensing applications including photometry, chemical and biomedial analysis, excimer laser monitoring and control, etc. Housed in a T05 hermetic package, it operates over 0 to 80° C and provides a responsivity of 100 V per µW. Matched to an output impedance of 50 Ω and operating from a nominal 5 V supply, it typically consumes 0.1 mA and will withstand output short circuit conditions for an indefinite period. (Source: *iti, International Technology & Innovation*, Vol. 30, No. 1, January/February 1993)

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Hall position sensors have 50 mA output current capacity

Operating over -40° to +150° C, the series SS400 suits brushless motors and harsh industrial applications such as print head and piston detection, door interlocks and rpm counting.

Built-in temperature compensation circuitry ensures stable operate and release points, customized to specific needs.

The compensation slope is designed to match the negative temperature coefficient of inexpensive magnets.

The Hall component is divided into four identical elements, quad-technology, so that any output signal due to stress to one element is nulled by an equal and opposite signal from one of the other elements.

Unipolar, bipolar and latching options are available. Sensitivity can be as low as 60 Gauss nominal at 25° C for the SS411A. Band gap regulation techniques are used to generate a constant DC supply to the IC from 3.8 to 24 V.

A 50 mA output current capacity allows direct connection to power circuitry without buffering or amplification. (Source: *iti, International Technology & Innovation*, Vol. 29, No. 7, July/August 1992)

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Airflow sensor high flow applications

The AWM5000 series features a venturi-type flow housing and measures airflows as high as 20 standard litres per minute (SLPM), while inducing a maximum pressure drop of 0.6 mbar.

Typical applications include medical insufflators, environmental sampling equipment, patient monitors and mass flow testing and calibration systems.

The sensors feature a rugged thermoplastic package designed to withstand common mode pressures of up to 6.9 bar, and a small sensing element, which can withstand 100 g of shock without compromising performance.

Separate snap-on ports can be modified with a minimum of tooling cost and performance impact, while the snap-in AMP connector provides reliable connection in demanding applications.

AWM5000 sensors interface directly with logic controllers without signal conditioning.

Each sensor contains circuitry that performs amplification, linearization, temperature compensation and gas calibration.

Solid state design overcomes problems of reliability, cost, power consumption and dust blockage, which occur in conventional hot wire devices.

Laser-trimmed resistors are positioned on either side of a heating element in a uniform flow channel. One resistor is heated by the airflow while the twin sensing element is cooled.

A microbridge circuit detects the variations in resistance caused by the temperature changes and outputs a voltage which is proportional to airflow. The sensors produce a 1-5 Vdc linear output, regardless of flow range or calibration gas. (Source: *iti, International Technology & Innovation*, Vol. 29, No. 8, Autumn/ Winter 1992)

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AC proximity sensor has no speed penalty

AC sensors are known for slow reaction times, but Taylor Dynamic Controls is now offering the Tri-Tronics Mity-Eye 4 msec response time design. The result is the capability to handle many more items a second that move past. The sensor has many other attractive features, including interchangeable lenses and light on, dark on, close operation and reflector operation. Ranges can be from 25 mm to 6 m (with reflector), and sensitivity adjustment is achieved in just four turns to make it faster. There is also a solid optical grade plastic lens block to help prevent condensation. (Source: *iti, International Technology & Innovation*, Vol. 31, No. 1, January/February 1994)

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IR sensor

Available with a laser aiming option for accurate pinpointing of the centre of the spot surface being measured, the Thermalert P3 and 1 micron special applications models are designed for thin film plastics and high temperature metal measurements.

The complete range now covers -100° through to 3,000° C.

The basic unit in 4-20 mA/RS232 transmitting form includes display and alarms or a full graphical display for QA purposes. *(Source: iti, InternationalTechnology & Innovation, Vol. 31, No. 1, January / February 1994)*

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Level sensor flips for highs or lows

Gentech's new level sensor can detect high or low levels. All you do to change it is install it the other way up. It is available in a range of materials, including Nylon 11, Nylon 66 and polypropylene. The sensor is operated by a reed switch capable of carrying 100 VA and has a variety of fittings and switch options. (Source: *iti, International Technology & Innovation*, Vol. 31, No. 1, January/February 1994)

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Non-contacting displacement measuring sensors

A new measurement technology has enabled Kaman to develop a precision non-contacting displacement measuring system to meet a requirement to measure the movement of undersea structures.

A batch of sensors has recently been installed by divers at the base of a structure in the North Sea.

The sensors, together with integral electronics, are developed from a product range providing full-scale measuring ranges from less than 1 mm to greater than 30 mm, with resolution capability to one part in 100,000 and long-term repeatability to one part in 10,000. (Source: *iti, International Technology & Innovation*, Vol. 31, No. 1, January/February 1994)

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Sensor tests pH levels

A versatile industrial pH sensor, the "Sensor for specific ion measurement in liquids", withstands temperatures between -20° and +120° C, measuring pH balances from 0 to 14.

Process industries and power companies, water and waste treatment plants and petrochemical companies will appreciate its ease of installation and high-quality materials.

This battery-powered sensor allows the pH signal to be sent long distances with no degradation. (Source: *iti, International Technology & Innovation*, Vol. 31, No. 1, January/February 1994)

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Right-angle sensor mounts on its side

Comet Series Perfect Prox right-angle viewing sensor ignores background reflections beyond two inches and requires less mounting space than forward-viewing models. Installing in a depth of less than one inch, the sensor can be used where standard tubular models will not fit. Although its body is tubular, the sensor has two flat sides, allowing it to be mounted on the side of conveyors and panels for greater protection.

This 18-mm photoelectric sensor operates in a diffuse-reflective mode and combines sharp optical cut-off with high excess gain to solve difficult application problems. Designed to provide fast response when sensing small targets, the device also has selectable light or dark operation capability. Universal voltage models are available that operate on 20 to 264 Vac or 15 to 30 Vdc. Other models operate on 10 to 30 Vdc only. Applications include material handling, packaging, conveying and food processing. Eaton Corp., 720 80th S.W., Everett, WA 98203, USA. Tel.: (800) 426-9184. (Source: *Machine Design*, 10 January 1994)

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CD pick-up serves as position sensor for absolute accuracy

An optical pick-up from an ordinary compact disc player can be used as a position sensor for absolute accuracy in measuring the position along a line or a curve on the surface of a reflecting object. The method was recently presented by Carl During and a team of post-graduate students at the Department of Machine Elements of the Royal Institute of Technology in Stockholm who have won an Innovation Cup prize for their discovery.

Typical applications for the sensor are measuring the angles of rotation of axes in industrial robots and the position of a rod in an actuator, says During, who emphasizes that there is no need for expensive scales or pre-treatment of the target surface. Another advantage is that the sensor is small and inexpensive.

The method is divided into two parts, an initial phase and a measuring phase. In the first phase, the signal pattern between the measurement boundaries is sampled and stored in a digital memory. The sample will correspond to an absolute position value if it is calibrated to a known reference. In an experimental arrangement with an aluminium disc, the recording was performed at a constant rotation speed, the speed being determined by an autocorrelation of the CD pick-up signal. The time difference between peaks gives the disc revolution time.

In the subsequent measuring phase the number of actual samples are correlated with the calibrated samples. The preliminary results obtained with the CD pick-up and the smooth surface of the rotating aluminium disc were well in agreement with the results from a laser rotary encoder, During says. An experimental arrangement is now being designed for rectilinear motions. (Source: *SIP, The Swedish-International Press Bureau*, May 1993)

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Micro inertial sensor technology

Prototypes of miniature sensors are under testing at the Massachusetts Institute of Technology's Charles Stark Draper Laboratory. Together with Rockwell International, it will develop devices to volume applications. Usage will be for antilock braking systems, full vehicle dynamic control and stabilizing camcorder images by controlling undesirable random movement of the camcorder's line-of-sight. (Abstracted from *Inside R&D*, 29 December 1993)

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Jena-Optronik develops solar sensor for Artemis satellite

The development of a highly precise solar sensor (PSS) is a joint project of DASA (Deutsche Aerospace: German Aerospace Company) and Jena-Optronik and is supported by the Federal Ministry for Research and Technology (BMFT). The PSS solar sensor is to be made of integral parts and key components of the new positioning, orbital control and data system ICDS (Integrated Control and Data System), which will be employed and tested within the Artemis ESA mission for future communications and earth observation satellites. The European Artemis technology satellite is supposed to be put into geosynchronous orbit in 1996 with the help of an Ariane launch rocket. The ICDS to be developed by DASA combines the control subsystem for the satellite's position and orbit control, the data processing subsystem and an on-board computer which can be programmed from the ground. This would make the autonomous position and orbit control possible as well as permit autonomous monitoring of the individual subsystems of the entire satellite. With the PSS the expenditure for the position and orbit control subsystem will be reduced, since this sensor weighs only 9 kg and uses only 8.6 watts of power. Through support of the development of the PSS in the nine federal States, the years of experience there in the area of space flight, especially from cooperative work with the former USSR would be effectively utilized. (Source: *VDI Nachrichten*, 6 August 1993)

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IR sensing card for YAG laser

Sumita Optical Glass Inc. and Mitsubishi Materials Corp. have jointly developed and started marketing an

IR sensing card, YAG Turkey, to inspect minuscule damage in YAG laser systems.

The IR sensing card works with an optical wavelength of 1.06 μm and converts non-visible YAG laser beams into visible light. It is specifically used to adjust and position the optical axes of laser beams. However, damage by the laser beam's energy when converting YAG laser beams into visible light is a problem. The threshold value of damage with respect to continuous laser beams is generally about 1.5 W/mm^2, so is generated by energy of comparatively low levels.

The new sensing card, due to the development of a special type of ceramic-based material, is capable of generating 30 W/mm^2, an output about 20 times that of conventional checker cards, and is not damaged even when continuously irradiated with light of high energy. The minimum light sensitivity is 3 W/mm^2, which enables sensing of laser beams of low to high outputs, and very accurate sensing of infrared rays within the wavelength range of 0.9-1.07 μm.

In addition to converting infrared beams into visible light beams, the card utilizes the wavelength up-conversion phenomenon and makes preliminary excitation of ultraviolet and other light beams unnecessary. It can even convert a laser beam under irradiation into visible light, so various adjustments are easy.

The card measures 90 mm x 54 mm, has a thickness of 5 mm and is equipped with an infrared ray-visible light conversion unit made of a ceramic fluorescent body. Further information is available from Sumita Optical Glass Inc., 4-7-25, Harigaya, Urawa City, Saitama Pref. 338. Tel.: (81) 48 832 3165; Fax: (81) 48 824 0734. (Source: *JETRO*, December 1993)

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Non-contact laser dimensional measurement

A range of non-contact distance measuring sensors, based on laser triangulation technology, is offered by the Swiss firm Techniques de Pointe SA. These have applications ranging from robotics and the auto industry to general metals engineering fields.

The "OPTImess" sensors were specifically developed for industrial applications that require exact measurements of such parameters as: position, dimension, vibration, thickness, etc.

Due to its performance and reliability, this family of sensors, highly insensitive to the variations of temperature and colour of the measured object, is said to open up new perspectives for the automation and the quality control of real-time monitoring.

The presentation of measurements done by the OPTImess is adaptable to each user's need. The results can be displayed or transmitted in analog or digital form to a control computer, or directly processed by the unit OPTIcontrol. (Source: *Metals Industry News*, Vol. 10, No. 4, December 1993)

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Plasma arc welding system integrates sensors and robots

An automated variable-polarity plasma arc (VPPA) welding system is reported to be under development at NASA's Marshall Space Flight Center, Alabama, in which sensors are integrated with computer-controlled equipment and a mathematical model of the weld. The sensors provide real-time information on the geometry of the weld bead, the location of the joint and the wire-feed entry. The model relates the geometry of the weld to critical process parameters.

A laser sensor for profiling the weld bead and controlling the rotation of the welding torch has been demonstrated, and a seam-tracking sensor based on artificial intelligence is also being evaluated. The system can be expanded to include automated opto-electronic inspection of the dimensions, peaking and mismatches of welds.

The system will coordinate more than 10 axes of motion and both macro and task-level programs are under development to simplify robot motion.

(Adapted from *NASA Tech Briefs*, November 1993. George C. Marshall Space Flight Center, AL 35812, USA. Tel.: (800) 437-5186.) (Source: *Advanced Materials & Processes*, 1/94)

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Chemical microsensors

Two scientists from Los Alamos National Laboratory report a new approach to develop ultrathin-film chemical microsensor materials. They anchored a covalently bound, self-assembled C_{60} multilayer on a surface acoustic wave (SAW) resonator via a siloxane bond linkage. It is hoped that this approach will provide solutions to some of the problems of thin-film chemical sensors produced using Langmuir-Blodgett and polymeric methods (e.g., long-term stability, poor adhesion to substrates, polymer swelling, non-uniformity). These sensors were found to be most selective to organic vapours such as decahydronaphthalene, perchloroethylene and toluene, as would be expected since they are good solvents for buckminsterfullerene. (Source: *Advanced Materials*, 1994, 6, No. 2)

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Quarter inch high-pixel EIS CCD image sensor

Matsushita Electrics Corp. has succeeded in commercializing the first quarter inch high-pixel electronic image stabilizer (EIS) CCD image sensor, MN3713 (NTSC) compatible with SVHS and Hi 8 system camcorders, which displays excellent image quality even during electronic camera-shake correction. The compact CCD image sensor with an optical size of a quarter inch is a functional device in commercializing camcorders.

Electric machinery manufacturers are engaged in research to reduce the effective diagonal lengths of image sensing areas where light is irradiated to produce compact and thin lenses matched to the focus points of CCD image sensors and to produce much more compact optical units than at present. However, it had been quite difficult to reduce optical device sizes without impairing the basic characteristics such as resolution, sensitivity and dynamic range.

Three technical points are involved in the successful contraction of the image sensor optical size. Firstly, a new type of high-sensitivity amplifier has been introduced that improves the sensitivity by 1.2 times compared to those of conventional counterparts. Secondly, the light collection efficiency of the on-chip lens that collects light has been improved by 20 per cent. Thirdly, the process device simulation method has been employed, by which the unit performance per unit area of the vertical CCD has been improved by 1.3 times compared to conventional counterparts. The development of this quarter inch CCD image sensor has reduced the volume of the movie unit by about 30 per cent, with a weight decrease of 150 g.

The EIS CCD image sensor integrates 330,000 pixels in an image sensing area of a quarter of an inch. In addition, outside the image sensing area is a special-purpose pixel domain of 230,000 pixels for correction of camera shake. A total of 560,000 pixels has been provided to enable the resolution, comparable to that of the SVHS and Hi 8 systems, to be maintained even during camera-shake correction. Further information is available from Matsushita Electronics Corporation, Publicity Section, 1-1, Saiwai-cho, Tatasuki City, Osaka 569. Tel.: (81) 726-82-5521. Fax: (81) 726-82-7611. (Source:*JETRO*, February 1994)

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Miniature switch capable of sensing accelerations and shocks

Koshin Ltd., a developer of special switches, has produced a miniature switch capable of sensing accelerations and shocks. This is a mechanical system using superminiature ball bearings and magnets, and when a force larger than the magnetic force is impressed on the balls sealed in a miniature cylinder, the electrically conductive balls move to switch the current on or off. The switch is usable as a product using oil and displaying a timer function.

In the acceleration switch, the balls are released from the magnet whenever an acceleration exceeding the preset magnitude is impressed in a fixed direction, by which two electrodes (on the cylinder inner walls) are connected to pass an electric current. The acceleration sensing level can be set by adjusting the distance between the balls and magnets.

Two acceleration switches were prepared, one of 440 gal and the other of 630 gal which are usable, for example, to work a brake whenever the speed of a belt conveyor increases abnormally.

The shock sensing switch principle of operation is the same. When an object fixed in position receives a shock with an acceleration of over 1,000 gal, the current is switched on instantaneously, so the switch is applicable, for example, as an automobile engine airbag inflation switch.

A timer has also been developed that operates the switching function after a fixed time (from 10 s to 30 mins) by filling the cylinder with oil and delaying the motions of the balls. No magnet is used and the switch is turned on and off by setting the timer upside down like a sand timepiece.

These switches have a diameter of 5.4-10.9 mm and a height of 5.5-9.4 mm. Compared to conventional types of switches using mercury, detailed setting is possible, mass production easy, and prices range from ¥229 to ¥357 each (in lots of 1,000 units). They can be incorporated into peripheral circuits. A unit capable of sensing only inclinations without misoperation even with slight vibrations is also available.

The company plans to continue its subcontracting business at its factory, while consigning the work of manufacturing special products to cooperating factories. The sales of special products are to be raised from the present 20 to 60 per cent by 1994. Since present crime prevention products are primarily for industrial use, the company is studying a plan to develop moderately priced systems for home use which apply miniature switches in combination with radio technology. Further information available from Koshin Ltd., 699-1, Shimo-Aotori, Higashi-Matsuyama City, Saitama Pref. 355. Tel.: (81) 493-24-3816. Fax: (81) 493-23-8357. (Source: *JETRO*, February 1994)

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Current sensing relay

Hawco have added a current sensing relay capable of monitoring loads up to 60 amps to their range of load sensing transducers.

Their model 4390 comprises a current ring through which the load carrying cable passes. When the current reaches the level set by the trip point a SPDT (20 A/240 V AC) relay is energized. An adjustable timer provides a delayed activation of the relay. It is ideal for monitoring motor under/over loads, heating element failures, phase loss, etc. The units are available in four current ranges with an optional calibrated trip point dial. Further information available from Hawco Ltd., Cathedral Hill Industrial Estate, Guildford, Surrey GU2 5YB, UK. Tel.: (0) 483 60606. Fax: (0) 483 575973. Telex: 859364. (Source: *Steel Times*, January 1994)

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New generation of IR-sensor

In order to meet the requirement for a cost-reduced version of Infrared-Sensor, Murata offers the series IRA-E100. Especially in combination with several filter types, with or without an integrated resistor, it gives the customer the possibility to find the best sensor for his applications, such as burglar alarms, electronic light switches, proximity applications, etc.

Additionally, Murata offers the quad sensor IRA-E009SXI using four elements for professional applications. All sensors show a high immunity against EMI-radiation and false triggering. (Source: *iti, International Technology Innovation*, Vol. 30, No. 1, January/February 1993)

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Silicon lifesavers

The Norwegian company SensoNor A.S., located near Horten on the Oslofjiord, has become the world's major manufacturer of "collision detectors" for vehicles equipped with airbags. The company has just signed a letter of intent with TRW Automotive, opening up the American market and the prospect of further expansion.

Airbag systems, which are intended to protect car drivers (and front-seat passengers), are dependent on sensors that warn them when a collision is in the process of taking place. These sensors must be both very sensitive and extremely reliable. They must send out a signal when deceleration is sufficiently rapid, but otherwise never. An airbag that inflates when a car is travelling at high speed on a motorway is no joke. Both conventional mechanical and electronic sensors are available today, but the electronic versions have proved to be the most reliable and cheapest.

The electronic sensors are based on silicon technology, an area in which Norway has long experience. In 1985, three of the staff of a "silicon company" in Horten started up a new company, which they called SensoNor A.S., to develop and manufacture silicon-based sensors. The Horten area, which is also known as Norway's "Silicon Valley", has seen the birth of a number of Norwegian electronics companies, many of which were started up on the basis of research results from SINTEF. Until now, SensoNor has supplied most of its chips to manufacturers of collision safety systems in Europe, where its share of the market is 80 per cent. The company's two biggest customers are Siemens and Electrolux. At present, the company is the sole supplier of semiconductor-based collision sensors to the European market, and 14 car manufacturers currently use systems that include SensoNor's sensors.

The memorandum of understanding that has just been signed with TRW Automotive will make SensoNor the dominant supplier of such sensors on the American market as well.

No fewer than 1.6 million vehicles are currently driving around with a sensor from SensoNor in their steering columns. Annual production is currently 2.5 million sensors, a figure that says much about the rate of expansion of the market. When deliveries to TRW start up, annual production will need to increase to around 5-6 million units.

SensoNor was listed on the Norwegian Stock Exchange in 1992. This step significantly increased the company's equity and allowed it to make considerable investments in equipment and personnel. Much of the company's research and development has been carried out in cooperation with SINTEF SI, and plans are afoot to increase collaboration in order to be able to satisfy rising demand in the future, both for deliveries to the automotive industry and for reliable and reasonably priced sensors for other applications. (Source: *GEMINI*, Norway, 1993)

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Smart vibration sensor

Vibrotector is a compact, intelligent sensor permanently mounted on a machine housing to measure vibration severity V_{eff} according to ISO 2372.

The user need only press a single button to display the effective velocity measurement, without the expense of continuous on-line monitoring or the effort of manual measurement at regular intervals.

The adjustable colour zones and tolerance market clearly indicate when more detailed analysis is required, freeing the user from the bookkeeping chores of individual measurements.

About the size of a golf ball, the sensor contains a transducer, a processor with analog/digital display and replaceable battery to power the sensor for several years.

The Vibrotector is made to withstand rough industrial environments; it is waterproof and dustproof to IP65 with an operating temperature range of -30° to 80° C. (Source: *iti, International Technology & Innovation*, Vol. 30, No. 1, January/February 1993)

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Sensors with fastest response times yet

Said to be the fastest device of its kind, the new CP18 cylindrical photoelectric control scans up to 30 metres and is intended for applications with restricted mounting space. These sensors could be used in conveyor control, jam detection, parts positioning and the like.

The patented, one-piece cylindrical housings are sealed to IP67 and threaded along their full length. They can be flush mounted. Light-focusing lenses refitted within the housings provide a flat sensing face reducing and cleaning time.

Response times are 1 ms for DC versions and 20 ms for AC versions. Light operate and dark operate options are available. (Source: *iti, International Technology & Innovation*, Vol. 29, No. 8, Autumn/Winter 1992)

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Smart sensors feature self-calibration/ID capabilities

Smart accelerometers are designed for use in systems where multiple sensors are used under central computer control. Two versions have been launched initially, the 9300-1000, which provides acceleration measurements up to 1,000 g in crash test applications, and the 9400-30, which is a SMART variable capacitance sensor. Key features include on-site self-test and calibration, self-identification and a common transducer interface. (Source: *iti, International Technology & Innovation*, Vol. 30, No. 1, January/February 1993)

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A smarter way to park

Parking a car in a garage once required a good eye, quick reflexes and some 2 x 4s on the floor. But now all it takes is an ultrasonic proximity sensor made by Solarwide Inc., Deerfield, Illinois, USA.

The battery-powered device, called Parkrite, looks like a traffic signal, having green, yellow and red lights. When it sees headlights it emits ultrasonic waves that reflect off approaching cars. As the car edges forward, Parkrite cycles from green to red, guiding the driver to a measured stop.

Setting up the device is easy: just park a car in the desired spot and press a button. The ultrasonic sensing system measures the distance to the car and stores it in memory. By timing the arrival of the returning echoes, the sensor can calculate distance to within an inch or two.

Solarwide is no stranger to putting ultrasonics into consumer products. Apart from its own line of ultrasonic tape measures, Solarwide private labels a variety of devices for Cooper Tools, Seiko Instruments and Bosch, making it one of the largest manufacturers of ultrasonic sensors.

The biggest challenge of the project, says one Solarwide engineer, was designing the set switch. Rather than disturb Parkrite's smooth surfaces with an ordinary push-button, the designers integrated the switch behind one of the plastic lenses. This required finding a lens thickness that would flex but not break when pressed. Helping in the design was Frogdesign Inc., an industrial design firm in Menlo Park, California. (Source: *Machine Design*, 26 November 1993)

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Infrared sensor keeps windscreens in the clear

Motorists will be able to forget about demisting the windscreen or switching on the wipers if a novel optical device developed by Sira becomes more popular.

The device, called a non-contact optical contamination sensor, detects misting on the inside of the windscreen and rainwater on the outside to automatically ensure that the screen is as clear as possible.

The sensor works by using IR signals from LEDs buried in the car's dashboard. The signals are reflected off the inside of the windscreen to a detector mounted inside the car roof.

The Sira engineers discovered that the IR beam is reflected or scattered by the windscreen depending on the flow of rainwater or the degree of misting inside. The more rainwater, the weaker the reflection: the more misting, the greater the scattering. Sira undertook the design and development of the sensor for a UK car manufacturer. The manufacturer wanted a device that could automatically control the action of a screen heater and the wiper rate of intermittently-operated windscreen wipers. (Source: *Engineering*, 8 January 1994)

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Sensing the coolest level

An optical liquid level sensor developed by Baumer Electric which can accurately measure the levels of translucent liquids is playing an important role in ice-cream production at Allied Frozen Foods.

The ice-cream firm keeps large tanks of skimmed milk at 65° C to ensure there is always enough available for production. Historically these tanks have been kept filled with a sufficient volume of milk by manual means, which has led to inaccuracies and even overflowing tanks. The company decided to install a semi-automatic system to control the maximum amount of liquid in the tank.

To do this, liquid level sensors which can operate accurately even when there is milky foam on the surface of the tank are required. The Baumer Electric sensor used by Allied Frozen Foods incorporates an integral IR transmitter and corresponding receiver. When the liquid level falls below the detection point, the internal geometry of the sensor causes the light to be reflected totally within the body of the device itself, travelling directly from the transmitter to the receiver. But when the liquid rises to the detection level it causes a change in the refractive index, and some or all of the light is deflected into the liquid away from the receiver. By adjusting the sensitivity of the device the milk level can be measured.

The sensitivity of the device is adjusted by a 20 turn precision potentiometer. This allows the measurement of the true liquid level, ignoring the foam on the surface. The fine adjustment also allows precise detection, despite the fact that milk dissipates only a small fraction of the transmitted light. (Source: *Engineering*, 6 January 1994)

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4. PUBLICATIONS

Sensor technology

This monthly update service follows advances in sensor technologies and their applications for companies in a broad range of industrial disciplines. It monitors and analyses breakthroughs in all areas of sensing - including machine vision, biosensors, instrumentation, corrosion detection, optoelectronics, image processing and more. ST describes how the growing array of temperature, pressure, proximity and biosensors can improve products and processes. The two monthly supplements, *Company to Watch* and *Keep an Eye On* offer additional insights. 12 issues: $565; outside North America $625. ST. (Technical Insights, Inc.)

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Technical Insights Inc. is publishing "*Advances in Environmental Sensors and Monitoring: Technologies and Opportunities to Meet Changing Government Regulations*". (Technical Insights Inc., Dept. RDD 013, P.O. Box 1304, Fort Lee, NJ 07024-9967, USA. Fax: (201) 568-8247)

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Chemical and biological sensors: opportunities for innovation

This monograph (by Teknekron Sensor Development Corp.), conceived with the small technology-based company in mind, provides the technical staff of a small firm with a multi-company report on the best opportunities for new business endeavours in chemical and biological sensors in the current technology-driven market. The field is full of fledgling, mostly privately-held, companies looking for markets in the chemical and processing industries, the automotive and power-generating industries, and the health-care industry. At the same time, users of industrial sensors have expressed disappointment in the lack of interest shown by sensor manufacturers in their specific industrial needs. There is a need for more well-planned contacts between sensor manufacturers and those who use them. This "Opportunities for Innovation" monograph is designed to assist in this process. (Order from *Innovator's Digest*, P.O. Box 15640, Plantation, FL 33318-5640; Tel.: (305) 473-9560, Fax: (305) 473-0544; Report No D323O; October 1991, 147 pp. Price: $299.00, prepaid.) (Source: *Innovator's Digest*; ISSN: 0890-300X)

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IISI technical reports

The IISI has recently published the papers presented at the technical exchange sessions of the Committee on Technology's twenty-fourth meeting at UNESID (Madrid, Spain) in May 1992, and the twenty-fifth regular meeting in Vienna, Austria in May 1993.

Rolls for Hot and Cold Strip Mills - Design, Manufacture, Performance and Influence on Product Quality (Madrid, 1992) includes six papers, which reflect the industry's need to meet ever-increasing demands on the dimensional precision and surface quality of hot and cold rolled strip products. Appended to the collection are the findings of a survey, carried out following the session, that on current rolling practice and future trends. Price BF 1,000 (non-members), BF 500 (IISI members)

Plant Diagnosis for Maintenance (Vienna, 1993) contains five papers reflecting the shift that has taken place in the maintenance field towards a more sophisticated predictive and diagnostic approach. Price: BF 1,500 (non-members), BF 750 (IISI members).

Near Net Shape Casting (Vienna, 1993) consists of eight papers from eight countries reflecting the potential that producers world-wide see for the near net shape casting group of technologies. Price: BF 1,500 (non-members), BF 750 (IISI members).

International Iron and Steel Institute, Library Services, Rue Colonel Bourg 120, B-1140 Brussels, Belgium. Tel.: 735 9075; Fax. 735 8012, Telex: 22639.

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New materials

The factors that impede the development and commercialization of new materials and steps that can be taken by government, industry and universities to overcome these impediments are the focus of this study conducted by the National Materials Advisory Board. It is available from National Academy Press, 2101 Constitution Avenue, NW Box 285, Washington DC 20055, USA.

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European research directories

The first complete directory of all scientific technical research and development projects supported by the European Community is now available from the Directorate General XIII. Almost 1,800 projects are described in the more than 400 page catalogue. A related publication is a directory of more than 1,400 enterprises and organizations from 17 European countries that are interested in finding partners for scientific and technical development. This information is also available on-line from the database CORDIS (Community Research and Development Information

Service) or from the new CORDIS CD-ROM Service, from which subscribers receive disks updating the information four times a year.

The *Catalogue of Research Projects* and the *Directory of Research Papers* can be obtained from bookshops or directly from the Office for Official Publications of the European Communities, 2 rue Mercier, L-2985 Luxembourg. Further information about these publications and about CORDIS is available by telephoning (+352) 3498 1240.

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Encyclopedic Dictionary of Chemical Technology. By Dorit Noether and Herman Noether. VCH, Weinheim, 1993. V, 297 pp., hardcover, DM 99, ISBN 0-89573-329-3.

This dictionary is orientated specifically towards communicators such as educators, reporters and writers, non-technical and specialized chemical practitioners, and professionals in chemical plants and research laboratories. It is also intended for interested workers in non-technological fields, such as economists and lawyers, and is consequently intended to serve as an interface between technologists and the lay public. The contents include relevant topics from the fuel industry, catalysts for economically important reactions, the fibre and textile industry, and fertilizers and pesticides for agriculture, with particular emphasis on biotechnology and pharmaceuticals.

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Carbon-Carbon Composites. By G. Savage. Chapman & Hall, London, 1993. 389 pp., hardcover, £40, ISBN 0-412-36150-7.

This book can be used as a reference by students, scientists, educators and engineers. It contains 10 chapters dealing with the structures of carbon, their fibrous textures, the processing of C/C composites through gaseous and liquid routes, their oxidation behaviour and protection, their physical and mechanical properties, the methods and techniques for their investigation and characterization, and also their fields of application, not forgetting the commercial aspects of the carbon-carbon industry.

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Advances in Powder Metallurgy & Particulate Materials 1993

A series of six volumes, containing a total of 135 papers, covers the proceedings of the 1993 international conference and exhibition on powder metallurgy and particulate materials, held in Nashville, Tennessee, USA, in 1992. Volume 1 covers powders, characterization, testing and quality control (31 papers, 416 pages, list price $150); volume 2 covers compaction, sintering and secondary operations (21 papers, 304 pages, list price $105); volume 3 covers modelling, design and computational methods (19 papers, 304 pages, list price $95); volume 4 covers processing, properties and applications (25 papers, 384 pages, list price $125); volume 5 covers powder injection moulding (18 papers, 272 pages, list price $90); and volume 6 covers specialty materials and composites (21 papers, 320 pages, list price $105). Special six-volume set - price: $550. From: Metal Powder Industries Federation, East Princeton, New Jersey, USA. Fax: +1 609 798 8523.

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Composite beams and columns

A new European publication on the design of composite beams and columns is available from The British Constructional Steelwork Association Ltd. (BCSA).

This publication presents useful information and worked examples on the design of composite beams and columns of the Eurocode 4 *Design of composite steel and concrete structures* (ENV 1994-1-1). The information is given in the form of a concise guide on the relevant aspects of Eurocode 4 that affect the design of composite beams and columns normally encountered in general building construction.

Copies of this European Convention for Constructional Steelwork publication (quote reference E72/93) are available, price £30 inclusive of postage and packing, from BCSA, 4 Whitehall Court, Westminster, London SW1A 2ES, UK.

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Introduction to Engineering Materials. Behaviour, Properties, and Selection. By G. T. Murray, California Polytechnic State University, San Luis Obispo. 1993, 688 pp., illustrated, $150. ISBN 0-8247-8965-2.

This concise, entirely up-to-date reference/text presents the fundamental science needed to understand the classification of materials and the limits of their properties in terms of temperature, strength, ductility, corrosion, and physical behaviour, while emphasizing materials processing, selection, and property measurement methods.

Providing the latest coverage of the most recent developments in the field, *Introduction to Engineering Materials* thoroughly discusses property definitions and measurement techniques; gives a general comparison of the different classes of materials and explicates specific similarities and differences; fully examines the properties and applications of each class of materials and tabulates the properties of the more important materials for easy referral; shows how to employ materials information sources such as technical publications, vendor data sheets, handbooks and computer databases; offers useful pedagogical features such as end-of-chapter definitions to facilitate review, homework problems, realistic examples, and lists of suggested readings; and much more. (Marcel Dekker Inc., 270 Madison Avenue, New York, NY 10016. Tel.: (212) 696-9000, Fax: (212) 685-4540. Hutgasse 4, Postfach 812, CH-4001, Basel, Switzerland. Tel.: 061-261-8482.)

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5. PAST EVENTS AND FUTURE MEETINGS

1994

11-12 April York, UK	Novel Synthesis and Processing of Ceramics (Organized by the Ceramic Science Committee of the Ceramic Industry Div. of the Institute of Materials, Regional Centre, Shelton House, Stoke Road, Shelton, Stoke-on-Trent, Staffordshire ST4 2DR. Fax: 0782-202421)
12-13 April Cambridge, UK	European Aerospace Non-destructive Testing Applications Forum (British Institute of NDT, 1 Spencer Parade, Northampton, NN1 5AA, UK)
18-22 April Freiburg, Germany	International Symposium on Optical Materials Technology for Energy Efficiency and Solar Energy Conversion (Fraunhofer Institute for Solar Energy Systems, Oltmannstrasse 5, D-79100 Freiburg, Germany. Fax: +49 (761) 4588 200)
1-6 May Palm Coast, FL USA	International Conference on Laser Processing of Materials (Engineering Foundation, 345 East 47th St., New York, NY 10017. Fax: (212) 706-7441)
15-17 May Pittsburgh, PA USA	Fundamentals and Analysis of New and Emerging Steelmaking Technologies (Iron and Steel Society, 410 Commonwealth Drive, P.O. Box 411, Warrendale, PA 15086, USA. Fax: (412) 776-0430)
16-17 May Montreal, Canada	12th Symposium on Composite Materials: Testing and Design (ASTM, 1916 Race Street, Philadelphia, PA 19103-1187. Fax: (215) 299-5413)
16-19 May Berlin, Germany	51st Annual World Magnesium Conference (Int. Magnesium Association, 1303 Vincent Place, Suite One, McLean, VA 22101. Fax: (703) 821-1824)
16-19 May San Diego, Calif. USA	Third International Conference on High-Temperature Intermetallics (ASM International, Materials Park, Ohio 44073-0002, USA. Fax: (216) 338-4634)
17-19 May Northampton, UK	Materials Testing '94 (British Institute of Non-destructive Testing, One Spencer Parade, Northampton NN1 5AA, UK)
23-25 May Les Diablerets, Switzerland	Polymers Theme of this symposium is molecular characterisation in relation to properties of polymeric systems. (ISPAC, 815 Don Gaspar, Sante Fe, NM 87501, USA. Fax: (505) 989-1073)
25 May Pittsburgh, PA USA	Recent Advances in Material Science and Technology - A tutorial seminar (Cosponsored by the Pittsburgh Golden Triangle Chapter of ASM International and the Basic Metals Processing Res. Inst. of the University of Pittsburgh. Tel.: (412) 941-1203)
29 May - 1 June Shanghai, China	ACerS Fifth Int. Symposium on Ceramic Materials and Components for Engines (ACerS, 735 Ceramic Place, P.O. Box 6136, Westerville, OH 43081-8720. Fax: 614-899-6109)
5-8 June Williamsburg, VA USA	Int. Conference on Intelligent Materials (Center for Intelligent Material Systems and Structures, Virginia Tech, Blacksburg, VA 24061-0261. Fax: (703) 231-2903)

6-9 June *Paris,* *France*	Powder Metallurgy World Congress & Exhibition (Societé Francaise de Metallurgie et de Matériaux, 1, rue Paul Cezanne, 75008 Paris, France)
13-16 June *Williamsburg, VA* *USA*	13th Biennial Conference on National Materials Policy "Technical Partnerships: A Road to Commercialization" (Sponsored by Fed. of Materials Societies. Fax: (202) 833-3014)
14-17 June *Sendai,* *Japan*	First International Congress on Science and Technology of Ironmaking (ICTSI '94) (Sponsored by the Iron and Steel Institute of Japan, Keidanren Kaikan, 3rd floor, 1-9-4, Otemachi, Chiyoda-ku, Tokyo 100, Japan. Fax: +81-3-3245-1355)
19 June - 2 July *Chania,* *Greece*	Materials Science and Implant Orthopedic Surgery (UCLA Medical Center, Dept. of Pathology, 10833 Le Conte Avenue, Los Angeles, CA 90024-1731. Fax: 310-206-5178)
21-23 June *Parsippany, NJ* *USA*	7th International SAMPE Electronic Materials and Processes Conference: Electronic Materials and Processes Revolution for a Peace Time World (SAMPE, P.O. Box 2459, Covina, CA 91722. Fax: (818) 332-8929)
21-24 June *West Point, NY* *USA*	NATO Workshop on Science and Technology of Rapid Solidification and Processing (NATO/ARW, University of Pennsylvania, Philadelphia, PA 19104. Fax: (215) 573-2128)
27 June - 1 July *Orlando, FL* *USA*	4th International Conference and Exhibition of the World Congress on Superconductivity (World Congress on Superconductivity, P.O. Box 27805, Houston. TX: 77227-7805. Fax: (713) 469-5788)
29 June - 1 July *Southampton,* *UK*	4th International Conference on Computer Aided Design in Composite Material Technology (Wessex Institute of Technology, Ashurst Lodge, Ashurst, Southampton S04 2AA. Fax: 44-703-292-853)
29 June - 4 July *Florence,* *Italy*	8th CIMTEC Forum on New Materials (Forum of New Materials, P.O. Box 174, 48018 Faenza, Italy. Fax: 39-546-664-138)
1-4 July *Florence,* *Italy*	Superconducting Materials Technology (World Ceramics Congress Secretariat, P.O. Box 174, I-48018 Faenza, Italy. Fax: +39-546-66-41-38)
3-7 July *Sundsvall,* *Sweden*	Symposium on Acoustic Emission from Composite Materials (University College of Sundsvall/Harnosand, Box 860, S-851 24, Sundsvall, Sweden. Fax: +46 (60) 126-640)
18-20 July *London,* *UK*	Technology - Conference on technology transfer and innovation (Transfer & Innovation, Hillside House, 79 London Street, Farringdon, Oxfordshire SN7 8AA. Fax: +44-367-242-831)
25-27 July *Sydney,* *Australia*	16th Australian Ceramic Conference (the American Ceramic Society is one of the the co-sponsors) (PMB1, Menai, NSW 2234, Australia. Fax: 612-543-7179)
14-19 August *New Hampton, NH* *USA*	Architectural Design of Ceramic Structures for Optimum Performance (Penn State, 201 Steidle Bldg., University Park, PA 16802. Fax: (814) 865-2917)

20-25 August Ontario, Canada	Materials Conference will explore the advances in materials production, and performance (Metallurgical Society, 3400 de Maisonneuve Blvd., West Suite 1210, Montreal, Quebec H3Z 3BS. Fax: +1 (514) 939-2714)
20-25 August Toronto, Canada	33rd Annual Conference of Metallurgists of CIM (Hatch Associates, 2800 Speakman Dr., Mississauga, Ontario L5K 2R7, Canada. Fax: +1 (905) 855-8270)
21-26 August Sendai, Japan	10th International Conference on the Strength of Materials (Department of Materials Science, Tohoku University, Sendai, Japan. Fax: 81-22-268-2949)
6-9 September Beijing, China	International Conference on Liquid Crystal Polymers (Chemical Society, P.O. Box 2709, Beijing, China. Fax: 486-1-2568157)
14-16 September Bordeaux, France	3rd World Conference on Science Parks - Science Parks and the Environment (International Association of Science Parks (IASP) and Association of University Related Research Parks (AURRP)). <u>Three issues</u>: Science Parks and Sustainable Development. Urban Development in Global Environment. Science and Regulations. (Bordeaux Congrès Service, 33300 Bordeaux-France. Fax: 33-56-43-17-76)
19-22 September Damman, Saudi Arabia	Plastics and Rubber Products and Technology (Dhahran International Exhibitions, Damman, Saudi Arabia Tel./Fax: 071-289-6982)
19-23 September Noordwijk, Netherlands	6th International Symposium on Materials in Space Environment (ESTEC Conference Bureau, P.O. Box 299, NL-2200 AG Noordwijk, Netherlands)
20-22 September Newark, DE USA	9th Technical Conference on Composite Materials (Center for Composite Materials, University Delaware, Newark DE, 19716. Fax: (302) 831-8525)
25-28 September Beijing, China	International Symposium and Exhibition on Shape Memory Materials (The Non-Ferrous Metals Society of China, Beijing, China. Fax: 86-1-851-5387)
28-30 September Pau, France	5th Meeting on Fire Retardant Polymers (Laboratoire de Chimie Organique Physique, Helioparc Pau-Pyrenées, 2, Avenue de Président Angot, 64000 Pau, France. Fax: 59-803-650)
3-6 October Rosemont, IL USA	ASM/TMS Materials Week '94 "The Total Materials Cycle" (ASM International, Materials Park, Ohio 44073)
9-14 October Sao Paulo, Brazil	Brazilian Metallurgy and Materials Society (ABM, Sao Paulo, Brazil. Fax: 011-240-4272)
10-12 October Lausanne, Switzerland	3rd International Symposium on Structural and Functional Gradient Materials (Swiss Federal Institute of Technology, Materials Dept., LMM, CH-1015 Lausanne, Switzerland. Fax: 41-21-693-46-64)
10-15 October Jinan, China	International Symposium on Fine Chemistry and Functional Polymers (Institute of Chemistry, Academica Sinica, Beijing, China)

17-19 October *Washington, DC* *USA*	Tungsten and Refractory Metals (Metal Powder Industries Federation, 105 College Rd. E., Princeton, NJ 08540-6692. Fax: (609) 987-8523)
24-28 October *Istanbul,* *Turkey*	2nd International Ceramics Congress (Istanbul Technical University, Faculty of Chemical and Metallurgical Engineering, Maslak 80626, Istanbul, Turkey. Fax: 90-212-276-1758)
8-11 November *New Delhi,* *India*	Global Changes and Stability in 2000 AD - Strategic Issues (IFTDO - Int. Federation of Training and Development Organizations and ISTD - Indian Society for Training and Development) (IFTDO World Conference, Indian Society for Training & Development, B-41, Institutional Area, New Mehrauli Road, New Delhi 110 016, India. Fax: 91-11-686-7607)
17-22 November *Warwick,* *UK*	3rd International Conference on Behaviour of Materials during Machining (Institute of Materials, 1 Carlton House Terrace, London, SW1Y 5DB, UK. Fax: 0-71-839-3576)
11-14 December *New Delhi,* *India*	4th International Seminar on Cement and Building Materials (National Council for Cement and Bldg. Materials, M-10, S. Extension II, Ring Road, New Delhi 110-049, India. Fax: 91-11-646-8868)

Advances in Materials Technology: Monitor

Reader Survey

The *Advances in Materials Technology: Monitor* has now been published since 1983. Although its mailing list is continuously updated as new requests for inclusion are received and changes of address are made as soon as notifications of such changes are received, I would be grateful if readers could reconfirm their interest in receiving this *Monitor*. Kindly, therefore, answer the questions below and mail this form to: Ms. A. Mannoia, Technology Development and Promotion Division, UNIDO, P.O. Box 300, A-1400 Vienna, Austria.

Computer access number of mailing list (see address label):

Name:

Position/title:

Address:

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1. Is the present address as indicated on the address label correct?

2. Do you wish to continue receiving issues of the *Advances in Materials Technology: Monitor*?

3. Which section in the *Monitor* is of particular interest to you?

4. Which additional subjects would you suggest to be included?

5. Would you like to see any sections deleted?

6. Have you access to some/most of the journals from which the information contained in the *Monitor* is drawn?

7. Is your copy of the *Monitor* passed on to friends/colleagues, etc.? If so, how many?

8. Do you have any information/suggestions etc. you would like to pass on to other readers?

9. Do you wish to have a specific "material" covered in a future *Monitor*?

10. Do you wish to contribute to the compilation of a future issue of the *Monitor*, be it with the main article or other information related to the relevant subject?

11. Please make any other comments or suggestions for improving the quality and usefulness of this *Monitor*.

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