CHARACTERISTICS OF FIBREOPTIC PRESSURE-SENSING CATHETERS

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ABSTRACT

An experimental fibreoptic pressure sensing probe is described and the characteristics of the components of the system are examined. Advantages of this type of probe include complete in vivo electrical isolation, high frequency response, miniaturization, ruggedness and low cost. The electroformed diaphragm is a major feature of the design.

INTRODUCTION

Currently used fluid-filled catheters generally have the pressure transducers mounted external to the vascular system, a situation which limits frequency response to a relatively low value (eg. typically 30 to 50 Hz). As a result considerable information, which may be quite useful in a diagnostic sense, is lost in the instrumentation.

Recently, several attempts have been made to incorporate miniaturized electrically and optically excited transducers directly into the catheter tip, in order to eliminate the low-pass filtering effect inherent in the fluid-filled devices.

Development of the electrically excited transducers has been mainly in the two sub-categories of strain-gauged diaphragms[1] and capacitance-change transducers[2]. Although elegantly designed and carefully constructed, devices of these types are quite delicate, expensive, and require an electrical input to the transducer tip and thus subject the patient to potential electrical shock hazards.

Optically excited probes, using fibreoptic light pipes, completely eliminate the shock hazard and show promise of being considerably cheaper and more rugged than their electrical counterparts. Several recent examples[3,4,5,6] utilize the basic approach of using light pipes as the optical energy carrier.

It is interesting to note that all transducers, electrically excited as well as optically excited designs, utilize a flexible diaphragm as the primary sensing element. The unusual diaphragm incorporated in the probe described in this paper is a major aspect of the probe design.

DESIGN CONSIDERATIONS

The design of an intravascular fibreoptic pressure probe requires an interesting combination of the principles of fluid dynamics, diaphragm characteristics, fibreoptics technology and optoelectronics. The fibreoptic pressure-sensing catheter design under consideration is shown schematically in Figure 1.

(a) Fluid Dynamics

Unfortunately, it appears that in cardiovascular pressure measurements very little distinction is made between stagnation (total) pressure or its components, the static pressure and dynamics pressure. For the moment we will accept the requirement for a probe which will measure the stagnation pressure.

In keeping with the physiological requirements for a cardiovascular pressure probe, the transducer should be capable of detecting changes in the range of -50 mmHg to +250 mmHg with a resolution of 0.5 mmHg or better.

(b) The Diaphragm

The diaphragm is a seemingly simple component of the system. However, this is somewhat deceptive since it is the primary transducing element, and the sensitivity, linearity and accuracy of the probe depend upon the diaphragm characteristics. Typically, very thin metallic or polyester diaphragms are generally used. Miller and Ferguson[4] investigated characteristics of possible diaphragm materials as a function of probe diameter, diaphragm thickness and deflection. Initially, with a flat edge-fixed diaphragm elastic bending stresses predominate and deflection is linear with pressure,but at larger deflections nonlinear stretching action becomes significant.

Diaphragm deflection is dependent on the fourth power of the diaphragm radius. It is obvious that this consideration imposes a limit on probe miniaturization. In addition, if linearity is to be preserved, deflection must occur in the bending mode only. The implication follows directly that a bellows type diaphragm would be mechanically desirable. A miniaturized, commercially-available bellows was tried by Miller and Ferguson. This bellows proved successful but had two major drawbacks: (1) eccentric side forces yielded an undesired signal, and (2) the bellows convolutions formed regions where blood could college and coagulate. Otherwise, the bellows was rugged, relatively low in cost, and easy to affix.

The present concept utilizes a custom-designed diaphragm which is even more rugged and much more suitable to the fluid dynamics involved. A protective cage is not necessary with the new design. Manufacture is by standard electroforming techniques and attachment to the probe is uncomplicated. This tip design is considered to be a major improvement in sensing diaphragms for catheter-mounted probes. A cross-section is shown in the insert in Figure 1.

(c) Fibreoptics and Light Path

Characteristics of fibreoptics are readily available in the literature and will not be treated in this summary.

It is evident that for maximum sensitivity:
1) the fibre diameter should be minimal,
2) a random distribution of input-output fibres should be used,
3) a large numerical aperture is desirable,
4) maximum specular reflection should be manufactured into the diaphragm reflective surface,
5) the fibres should be imbedded in a flexible and opaque matrix conduit to eliminate optical cross-talk,
6) the light source, detector and fibre spectral characteristics should be carefully matched.

(d) Optoelectronics

Recent advances in solid-state radiation detector technology have yielded a wide choice of low-voltage and compact detectors. PIN photodiodes, phototransistors, photo-FETs and photo-Darlington amplifiers have linearity and response times quite adequate for the purpose. For this particular design we have chosen commercially available phototransistors (Motorola MRD 300) which have the capability of being base-biased for increased linearity and sensitivity when used with low-level signals.

Currently available differential operational-amplifiers offer all of the characteristics required for coupling the optoelectronic detectors to the readout devices. Low input noise, low temperature and time drifts and excellent common-mode rejection capabilities of op-amps combine with their small sizes and low-voltage power requirements to make them desirable components. Variations in detector signals caused by light source fluctuations will be common-mode rejected.

High signal-to-noise ratios are required for probes of this type. If a resolution of 0.1 mmHg is required in the range of 300 mmHg, a S/N ratio of at least 3×10^3 is required. For a 50 mmHg per volt transduced and amplified signal, the resolution specified then demands an output noise level lower than 2 mv. This is quite a reasonable figure. For the prototype amplifiers, Fairchild ADO 72B op-amps were used.

Output signal levels are compatible with most standard oscilloscopes and/or recorders.

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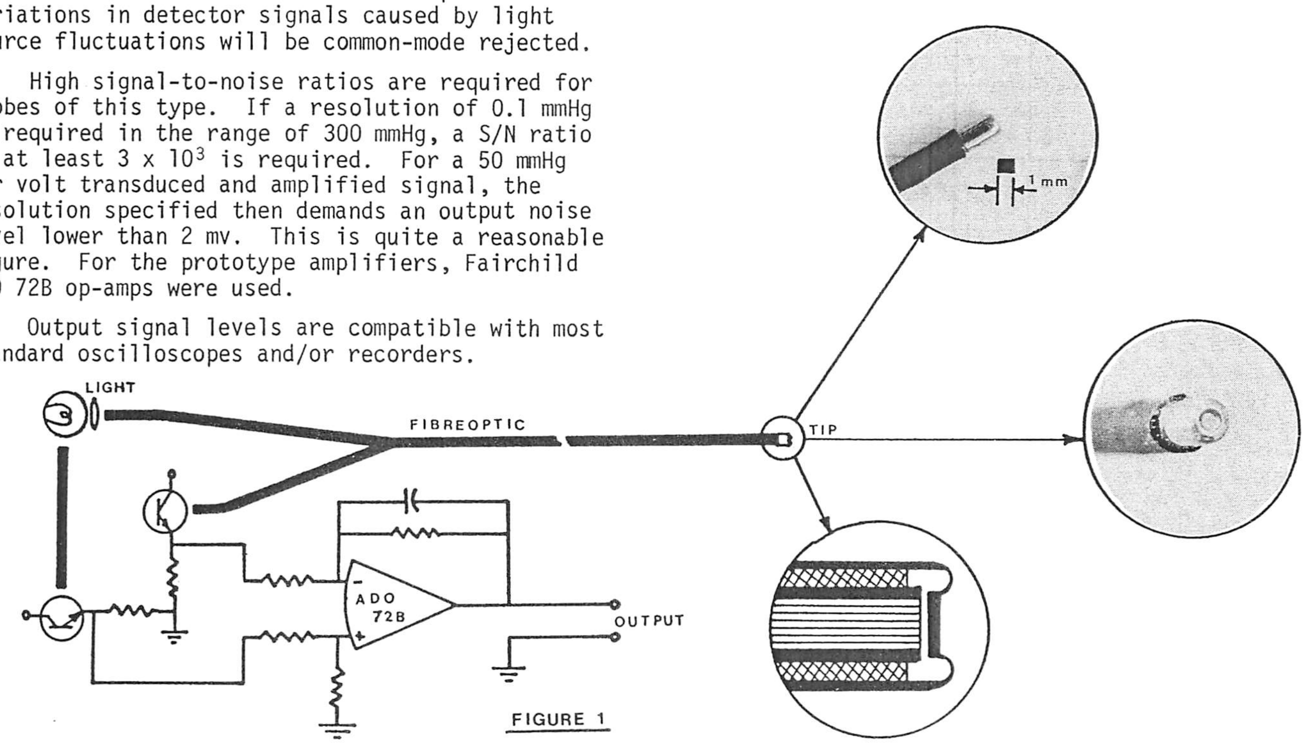

FIGURE 1