distance can be varied for a given pressure range in a systematic manner until the greatest intensity change is realized. Some results of this type of analysis are shown in Fig. 3. The diameter was set at 0.794 cm, where output was a maximum, and the thickness specified at 5.08×10^{-3} cm. Work is now being done with a completely circular fiber optic probe with annular detector area; this geometry simplifies the integration scheme considerably.

Conclusions

The design and operation of a fiber optic transducer have been described in detail. The highest sensitivity in terms of transducer output was obtained using a tungsten filament light source and a CdS photodetector with a 0.794-cm dia, 5.08×10^{-3} cm thick diaphragm (1145-H19 aluminum) at a probe distance relative to the reflecting diaphragm of 2.5 cm. A study of the effect of varying diaphragm diameter revealed that the optimum diameter is the one which equals the diameter of the source-detector probe bundle for the probe geometry and fiber arrangement studied here. The transducer output was generally nonlinear, and present work is aimed at determining the source of nonlinear effects. The influence of varying diaphragm-to-probe distance was also investigated. Minimum sensitivity occurred where the intensity of the light reflected from the diaphragm as a function of probe distance was maximum. Increasing the probe distance beyond this point tended to increase the transducer sensitivity, until at very large probe distances a trade-off was made with high light losses. The dynamic response of the fiber optic transducer was found to be superior to a laboratory-grade strain gage transducer. The fiber optic transducer had a faster response time and gave a much higher output voltage than the strain gage transducer (tenths of volts compared to millivolts). A mathematical model has been formulated which demonstrates the working principles of the fiber optic transducer. By varying such parameters as diaphragm diameter, thickness, probe distance, and fiber geometry, an optimum design could be predicted mathematically when other physical dimensions for a required application are known. In general it was found that the fiber optic transducer has potential advantages over other commercially available pressure transducers.

There are many situations in research and industry in which a transducer of this type would be preferred over other types. The advantages which dictate this preference are as follows:

(1) Excluding diaphragm flexure, there are no moving parts. The lack of moving parts and fragile electronics allows a ruggedness of design incomparable to any other transducer.

(2) Data are transmitted at the speed of light.

(3) The light guides can be any length, thus the electronics can be located remotely from the transducer. This is of special importance in hostile environments, where temperature extremes, vibrations, or other factors would affect the electronics.

(4) The diameter of the transducer can be as small as a needle for point pressure measurements, or as large as practical limits dictate for bulk pressure measurements.

(5) The temperature sensitivity is minimal and limited only to the physical limits of the materials of which the transducer is constructed.

Finally, the transducer cost is an important consideration. The experimental model used in this work, including light source, photodetector, a specially machined transducer housing, diaphragm assembly, and probe with 4.3 m of plastic light guides cost less than $40. However, the cost of the light guides is a substantial part of this total. For applications in which the light guide lengths would be relatively short, say 3 m or less, this would be an extremely economical transducer. However, if it were necessary to locate the electronics a great distance from the transducer, special low-loss fibers would have to be used, substantially increasing the cost. An additional increase in cost would be necessitated if the light source and detector were of a much higher quality than those used here. On the other hand, if such a transducer with read-out instrumentation were mass produced, overall cost could be reduced again.

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DISCUSSION

M. W. Hyer[2]

Messrs. Pahler and Roberts should be commended for their work in contributing to the development of the fiber optic pressure transducer.

The authors pointed out the advantages of such a transducer when it operates in hostile environments such as extreme temperatures. It should be emphasized that such a transducer might be the only option available when working in an environment with magnetic and electric fields. Electromagnetic fields can affect adversely the operation of inductive and capacitive probes, particularly if eddy currents are generated in the object whose displacement is being measured. The optical transducer, of course, would not be affected.

It is understandable that the absolute frequency response is difficult to measure. However, it would be worth making a theoretical prediction based upon diaphragm dynamics and the response of the electronic circuitry in order to compare this type of transducer to other transducers, since the former device might find application in a control system where superior response characteristics are a valuable feature.

A mathematical model was formulated which seemed to correlate fairly well with experimental observation, particularly in regard to the circular optic source and to the annular detector area probe. Since optimum design is an important consideration, it would be interesting to adapt the mathematical model to an optimization scheme, maximizing, say, the sensitivity or dynamic pressure range. The scheme would determine the diaphragm characteristics and the probe-to-diaphragm distance for the particular optimal condition.

F. A. Kern[3]

From this discusser's review of the paper, he has the following comments. This paper deals with an area of transducer technology which should grow and develop over the next few years and in that light make a contribution to the available data base.

However, the discusser does not think that the intent of the paper,

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to suggest emphatically that these transducers have potential for superior performance, has been achieved. First, the limited test results do not support the statement that "a transducer of this type can be designed by choosing a proper diaphragm diameter, thickness, and material." For example, when the mature capacitance-type pressure transducer technology was extended from a 15-psi to a 100-psi range—a range easily obtained with strain gage transducer technology—diaphragm design, material processing, and fabrication techniques changed sharply. Although the strain gage transducer technology may support the statement, one must be careful of an overgeneralization. The discusser does not think the data presented in Fig. 4 support the conclusions. The majority of commercially available strain gage-type transducers in this pressure range have natural frequencies in excess of 2000 Hz and have frequency responses flat to at least 400 Hz. Therefore, the strain gage transducer should be demonstrating good dynamic signal fidelity beyond 15 Hz. Sufficient data describing the dynamic test arrangement are not presented in this paper so the test results cannot be fully understood. The data presented in Fig. 4(*a*) suggest other problems, since the phase difference curve is not smooth as might be expected. Simple calculations comparing the fiber optic transducer and a ½ in.-dia flush diaphragm transducer by varying the natural frequency and the damping factors do not demonstrate the large-phase differences shown in the data.

The tests performed to optimize optically this configuration were good, as was the development of the theoretical model.

The comment in the conclusion noting the higher output of the fiber optic transducer compared to that of a strain gage transducer is only a comparative observation based upon the choice of reference transducer, since many transducers have outputs much higher. The advantages listed for using a fiber optic transducer do not fully set this approach apart from the use of other transducers. For example, the comment on temperature sensitivity—number 5—is, in general, true for both types of transducers. This might have been better supported if a thermal effects experiment had been included as part of the development program. For example, plastic fiber optics are limited to thermal environments less than 200° F. Glass fibers can withstand higher temperatures as pointed out; they are more expensive per unit length but require a more difficult preparation of the fiber end.

In summary, the results presented in this paper describe a good development. Continued work in the areas suggested by the authors, coupled with additional dynamic and thermal tests, will demonstrate a pressure measurement technology that will be useful in the industry.

Authors' Closure

Regarding Professor Hyer's comment on transducer dynamic analysis, we have developed an improved optimization scheme which includes the response of the electronic circuitry used with the pressure transducer. The results of this improved optimization scheme have not been published because we have not yet produced the experimental data to verify the improved analytic model.

In our enthusiasm for the simplicity and technical advantages of the fiber optic pressure transducer, we failed to reckon with the difficulties of new product development in a field where very good instruments are already available. After talking with several transducer manufacturers, we must concede Mr. Kern's point that substantial inducement is required to achieve materials processing and fabrication changes in a transducer industry. We have not, for example, accomplished the high temperature tests that would be necessary to substantiate the expected improved performance at elevated temperatures.

Regarding the comment on dynamic response of the transducer: While our data is preliminary, we were satisfied that the fiber optic pressure transducer was more sensitive to small differential pressures than the strain gage transducer which was used for comparison. The harmonic pressure generator used in the test displayed rapidly decaying pressure amplitudes with increasing frequency. The limited result displayed in Fig. 4(*b*) is due to the inability of the strain gage transducer to resolve the small differential pressures which occur beyond 15 Hz. The fiber optic transducer was able to resolve the small differential pressures up to 70 Hz. As to the phase differences displayed in Fig. 4(*a*), we have no further explanation beyond the citing of diaphragm mass differences; however, it is possible that circuit differences might be adding to the phase measurements.