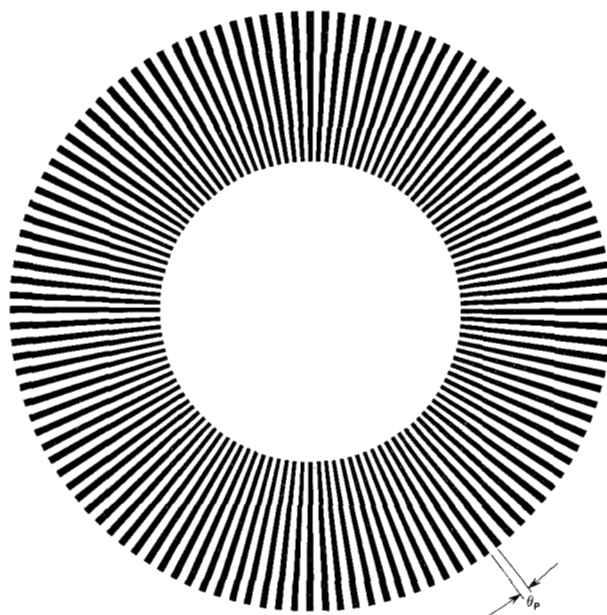


Design of a Moiré Fringe Torque Transducer

A problem often encountered in instrumentation is that of measuring the torque in a rotating shaft. Shortcomings exist in most current instrumentation techniques because of the necessity of a physical connection to the transducer. This problem can be overcome by using an optical device that has the advantage of having no physical connection to the shaft. A family of optical devices exhibiting the Moiré fringe effect has been applied in the measurement of linear and rotational displacement, elastic and plastic strain, and surface flatness. The device in this family that is most useful in measuring rotational displacement is the radial line pattern, as shown in Fig. 1.

Figure 1 Radial line pattern used to generate Moiré pattern.



The pattern consists of equally spaced radial lines that divide the piece into alternately opaque and transparent areas. When two equivalent patterns of this type are concentrically superimposed, the total transparent area of the combination is dependent upon the relative angular position of the two patterns and varies as shown in Fig. 2. The relative angular displacement can then be determined by measuring the transparent area of the pattern combination. For a relative displacement less than the angle between radial lines, the transparent area is directly proportional to displacement. A relative displacement greater than the angle between radial lines can be measured by counting the cycles through which the transparent area has varied. These techniques for measuring relative displacement have been applied in the design of a torque transducer that converts the variation in the angle of twist in a stressed shaft into a variation in the transparent area of the Moiré pattern. The variation in transparent area is sensed with a solar cell and a light source that do not rotate with the shaft.

Design procedure

In designing a torque transducer of this type, the torque capacity, the full scale signal, and the noise level must be considered. The basic configuration chosen for the transducer is shown in Fig. 3.

The radial line patterns are mounted on collars which, in turn, mount on the gage arbors. The collars are adjustable to provide for centering the patterns. The gage arbors are fixed to the shaft with set screws, the position of which determines the gage length of the transducer.

When it is necessary that the transducer have a linear relationship between torque and transparent area, the torque capacity is determined by the pattern size, the shaft stiffness, and the gage length. The governing equation

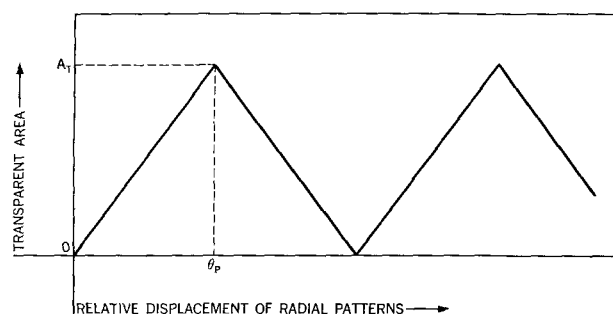


Figure 2 Transparent area of Moiré pattern vs. relative displacement of the two radial line patterns.

relating these variables is:

$$T_c = \theta_P \left(\frac{\pi}{180} \right) \left(\frac{G D^4}{32 L} \right). \quad (1)$$

In most cases the shaft diameter is fixed, and the gage length and pattern size are determined, based on estimates of the needed torque capacity. Size restrictions (such as inertia) must be considered at this stage, and will aid in making a final choice of dimensions.

When more accuracy is desired, the transparent area can be allowed to vary through several cycles. The torque required to obtain a relative displacement equivalent to one cycle is determined by Eq. (1) and the relation

$$T_{Cycle} = 2T_c. \quad (2)$$

When the device is used in this manner, the torque capacity of the transducer is limited only by the strength of the shaft.

The choice of pickup used in the transducer is important not only for the magnitude of the signal, but also for the magnitude of noise due to geometry. A solar cell and light source arrangement can be used with the circuitry¹ in Fig. 4. With this circuit the output voltage is proportional to the illuminated area of the solar cell. The illuminated area is in turn proportional to the transparent area of the Moiré pattern. Hence, the output voltage is proportional to the transparent area of the Moiré pattern.

It is desirable that the area of the solar cell be as large as possible relative to the area of the Moiré pattern because of the noise engendered by the lines entering and leaving the area between the solar cell and the light source. One way of achieving good results is to position two solar cells diametrically opposite each other. A ripple voltage of less than 1% of full scale voltage can be obtained in this manner.² The nature of the light source for this arrangement is not of great importance because the patterns are placed together. If the patterns were separated, a collimated source would be necessary to eliminate optical crosstalk in the patterns.

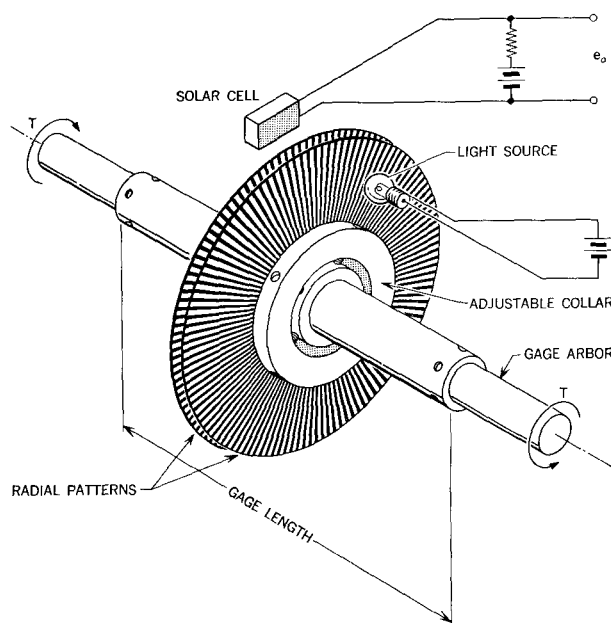
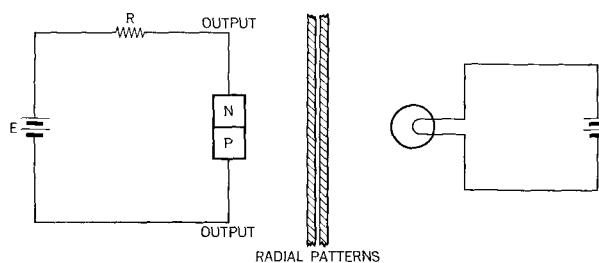


Figure 3 Basic configuration of the transducer.

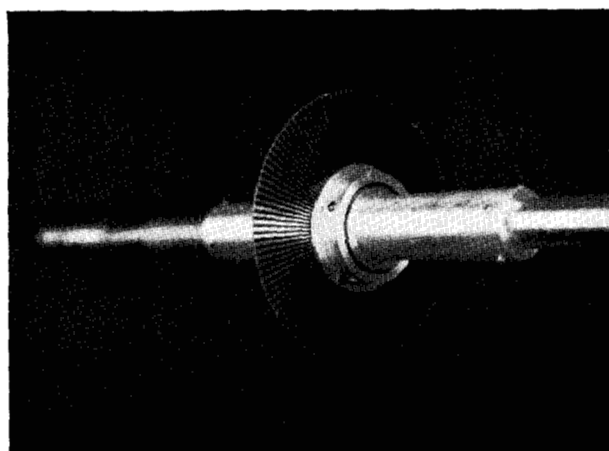
Figure 4 Circuitry used with solar cell pickup.



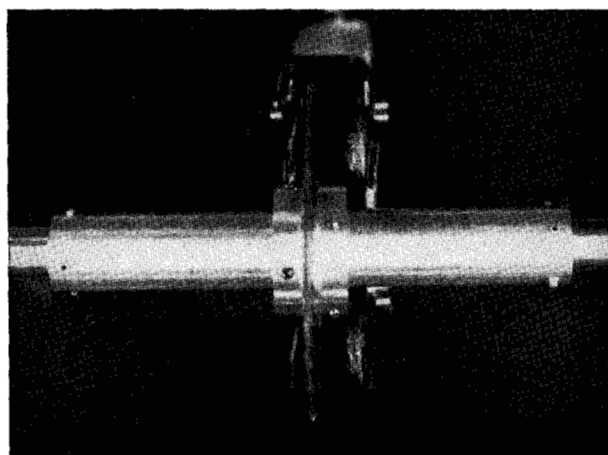
Test results

There are two principal types of noise in this transducer. These are (1) voltage ripple due to the pattern lines entering and leaving the solar cell area; and (2) a cyclic variation caused by imperfect patterns and imperfect pattern concentricity. The ripple can be minimized by choosing a solar cell with a large area. The cyclic variation can be minimized by careful adjustment of each pattern for concentricity with the shaft. Pattern quality will affect both types of noise.

This transducer has been used to measure the dynamic torque in a drive shaft subjected to a clutching load. The transducer and drive shaft are shown in Fig. 5. The diameter of the drive shaft is 0.500 in., and the gage length of the transducer is 4 in. The patterns are 1.5° radial line patterns. The shaft diameter is reduced to 0.250 in. between the set screws to obtain more relative deflection. A full-scale output of 300 mV, a ripple voltage of 2 mV and a



(a)



(b)

Figure 5 (a) Transducer connected to drive shaft; (b) same device with solar cell pickup in place.

cyclic variation of 20 mV are representative values for this configuration.

It should be noted that the cyclic variation is dependent on the angular position of the shaft and is a periodic function. Its effect can be accounted for and removed. In general this will be necessary, since perfect adjustment is difficult to achieve.

The dynamic characteristics of the transducer were not investigated thoroughly, since the inertia of the transducer was less than 1% of the total inertia of the drive shaft and pulley system to which it was connected. However, successful application of the device does necessitate consideration of transient response. This must be considered at the design stage for each application, because the response of the transducer is a function of the system in which it is installed.

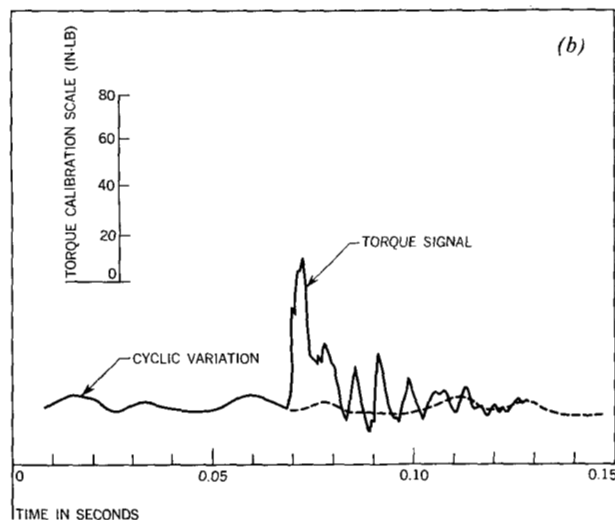
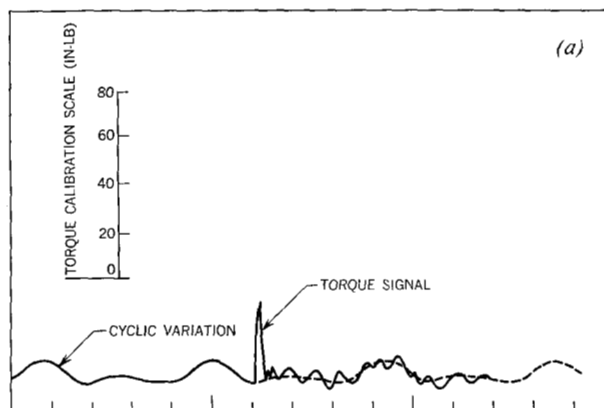


Figure 6 (a) and (b) Representative traces of torque vs. time.

Some examples of the data obtained in this application are shown in Fig. 6. The calibration was done with the transducer mounted and connected to the recording equipment. A standard torque wrench was sufficient for this particular application.

Conclusions

This transducer has advantages for certain applications where conventional techniques are not adequate. One such application is the measurement of torque variation in a rotating shaft when a physical connection to the shaft is undesirable. The transducer could also be useful when used with high speed movies. This use can give the engineer a visual indication of torque while the mechanism action that provides the loading is also being viewed. Disadvantages of the transducer include the need to design

for each particular application and the difficulty in adjustment which eliminates some of the very small shaft-size applications. The technique described here is by no means complete. It is hoped that further effort will refine the design so that its potential contribution to instrumentation can be more fully achieved.

Nomenclature

A_T	Transparent area of Moiré pattern formed by two radial line patterns.
θ_P	Included angle of adjacent radial lines in radial line pattern.
D	Shaft diameter.
L	Length of shaft over which the angle of twist is to be measured (gage length).

G	Shaft modulus of rigidity.
T_C	Torque capacity of transducer.
$T_{C_{\theta_P}}$	Torque required to twist shaft through an angle of $2 \theta_P$.
T_S	Torque in shaft.

References

1. H. W. Simpson, "Principles of Instrumentation and Measurement," *ASME Paper No. 64-MECH-39*.
2. "Electro-Optical Moiré Fringe Transducer," *Electromechanical Design*, Dec. 1964, p. 26.

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