ON A SIMPLIFIED MEMBRANE PRESSURE GAUGE

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The precise membrane pressure gauge has been constructed by R. Kiyama and K. Suzuki[1] on the principle that the pressure on a steel membrane, the deflection of the membrane being magnified by two steps of levers, is measured by the displacement of the light spot. However, the pressure gauge, due to the principle, has some defects, that is, it is laborious to construct with sufficient stability, and it must always be set in such a manner that the surface of the membrane is horizontal, and it cannot perfectly follow rapid pressure changes.

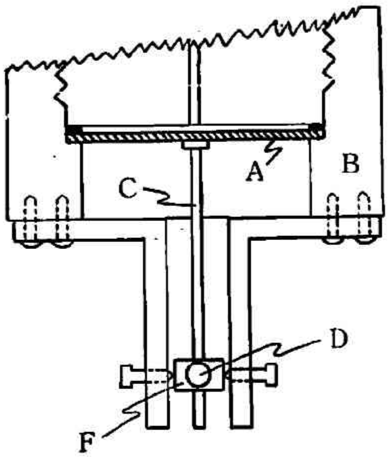

Fig. 1 The apparatus

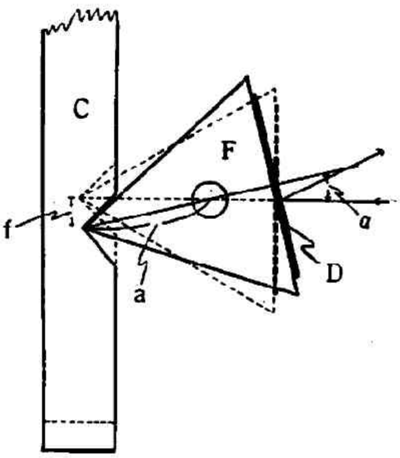

Fig. 2 The rotation of the mirror

The authors, therefore, have constructed a new simplified membrane pressure gauge to overcome these defects, and have successfully observed very rapid pressure changes by employing it with a wire resistance strain meter.

The apparatus is shown in Fig. 1. A spring steel membrane A is fixed in cylindrical case B (72mm and 44mm in outer and inner diameters respectively), and a brass rod C (2mm in diameter and 55mm in length) is connected to the membrane A at the center. A mirror D is cemented on the surface of a trigonal piece F whose one edge fits with a dent on the rod C, and the piece F rotates about two bolts as an axis (Fig. 2). The displacements of the light spot due to the rotation of the mirror are read on a scale at 1m distant from the mirror.

The radial stress of the circumference σ and the displacement at the center of membrane f due to the pressure P are shown by the following equations respectively[2]:

$$\sigma=\frac{3}{4}\frac{Pr^2}{t^2}, \qquad (1)$$

$$f=\frac{3}{16}\frac{r^4P}{Em^2t^3}(m^2-1), \qquad (2)$$

where the radius is r and the thickness of the membrane t, reciprocal Poisson's ratio m and coefficient

1) R. Kiyama and K. Suzuki, *This Journal*, 21, 99 (1951)
2) A. Morley, *Strength of Materials*, p. 430, 431 (1926)

of elasticity E. The maximum pressure P_{max} below which the linear relation holds between f and P, as shown by Equation (2), is obtained from Equation (1), by substituting the elastic limits of the material of the membrane to σ (for the spring steel, σ=8293kg/cm^2 [1]). Assuming the distance between the mirror and the scale to be l, the rotating angle of the mirror α and the displacement of light spot on the scale x due to the displacement f at the center of membrane are, as shown in Fig. 2, given by the following equations respectively:

$$\tan\alpha=\frac{f}{a}, \tag{3}$$

$$x=l\tan 2\alpha, \tag{4}$$

where a is the rotating radius of the brass piece F. Since f is much shorter than a, and so α is also small, and hence, within the limiting value f_{max}, the displacement at the center of the membrane corresponding to P_{max}, x is able to be given approximately by the following equation:

$$x=2f\frac{l}{a}. \tag{5}$$

Since a and l are constants, x is linear to f and hence linear to pressure P within the limit of elasticity of the materials of the membrane.

From the results of the measurement with the membrane of the radius 2.2 cm and thickness 0.1 cm, the displacement of the light spot has been found, as shown by line a in Fig. 3, satisfying the linearity to pressure, and its pressure sensitivity has been 1.23 cm per 1 kg/cm^2 corresponding to calculated value 1.13 cm from Equations (2) and (5) (r=2.2 cm, t=0.1 cm, a=0.3 cm, l=100 cm, σ=8293 kg/cm^2 E=2,000,000 kg/cm^2, and m=3).

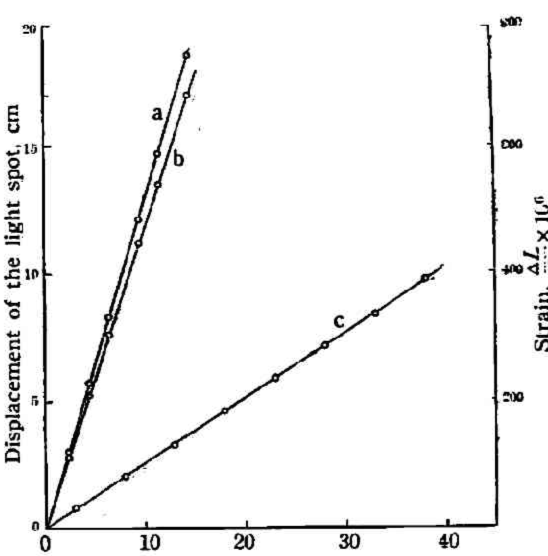

Fig. 3 The relations among various methods of pressure measuring

a : Bourdon gauge–optical membrane gauge (t=0.1 cm, r=2.2 cm; a=0.3 cm, l=100 cm)

b : Bourdon gauge–strain gauge (t=0.1 cm, Type-S_{24})

c : 〃 〃 (t=0.3 cm, Type-S_{24})

In the case that the rapid displacement of the light spot, due to the rapid pressure change, can not be observed by naked eye, a strain gauge is cemented on the surface of the membrane, and the pressure change can be recorded by the strain gauge and an electromagnetic oscillograph*. The strain gauge consists of a resistor wire whose resistance changes with the strain of the membrane owing to the changes in the length and the cross-sectional area of the wire, and thus pressure is measured by means of the wire resistance strain meter**, and recorded on oscillographic paper.

The results of the measurements on the relations of the strain and the pressure, employing the membranes of 0.1 and 0.3 cm in thickness on which the strain gauges (size 4×4 mm, 120 Ω, and G. F. 1.82***) are cemented, are shown in Fig. 3 (lines b and c). The strain has been linear to the pressure****. The result of the measurement of rapid pressure change by employing electromagnetic oscillograph is shown in Fig. 4. The rapid pressure change within about 1/50 sec, as shown by e in Fig. 4, can be recorded in the curve of increasing pressure from 0 to 10 kg/cm².

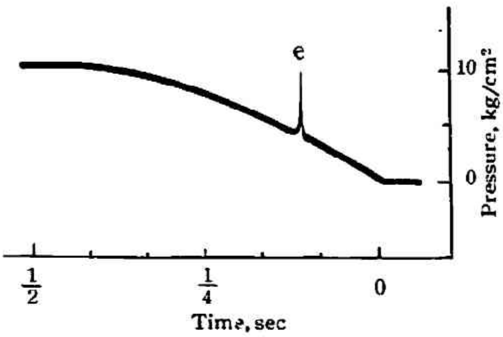

Fig. 4 The pressure-time curve recorded on the oscillographic paper

For certifications on the delay for pressure (strain) recording of the strain gauge method and on its stability, experiments have been performed on pressure change curves recorded by comparing with the pressure gauge based on electric capacity change, which consists of an electric condensor, having a movable membrane as one electrode plate, an oscillator and an amplifier, and which has been confirmed to show no delay for pressure recording.[3] From the results recorded by both methods of the pressure change from 0 to 18 kg/cm² during about 1.75 sec, as shown in Fig. 5, it has been confirmed that, comparing with the recording by the pressure gauge due to capacity change (curve g), the recording by the strain meter (curve h) has shown neither any delay for pressure recording nor any clear difference in its stability, and also that if carefully cemented, the strain gauge has been satisfactorily used for recording the strain of the membrane and so the pressure

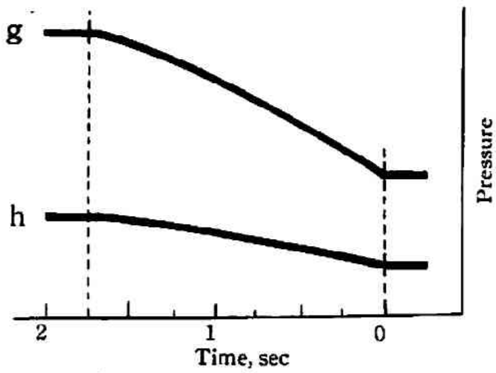

Fig. 5 Comparison of the pressure recordings
g : by the pressure gauge based on electric capacity change
h : by the membrane gauge and the strain meter

* H-Type vibrator, made by Yokogawa Elec. Works Co. Ltd., Tokyo, Japan. (sensitivity : 75 μA per 1 mm deflection)

** DS6-R Type, made by Shinkoh Communication Ind. Co. Ltd., Tokyo, Japan.

*** S_{24} Type, made by Shinkoh Communication Ind. Co. Ltd., Tokyo, Japan, G.F. $=\frac{\Delta R}{R}\Big/\frac{\Delta L}{L}$, where L is the length and R is the value of resistance of the strain gauge.

**** The strain ΔL may be taken to be linear to f in the range of small f.

3) J. Osugi, *This Journal*, 21, (86 1951)

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change.

It is confirmed from these results that the pressure gauge which can be used for desired high pressures with proper sensitivity is got comparatively easily, by selecting the proper thickness of the membrane, and employing the strain meter. The present pressure gauge is possible to be used for measuring the pressure from distant place without decreasing its precision, and employing also the oscillograph, the gauge is able to be used satisfactorily for recording very rapid changes of high pressures.

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