Study on the Measurement of Tunnels Head Loss

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Study on the Measurement of Tunnels Head Loss

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In order to estimate the head loss of an underground or a vehicle tunnel, it is required to measure the difference of absolute pressure between two points. The authors, therefore, had studied a measuring device for that purpose. The principle of this device is based on the fact that as air is confined in a enclosure of constant temperature and volume, the head loss between two points can be determined by comparing the absolute pressure of the each point with the confined air pressure. Such device had been used to measure the head loss at some mines and tunnels, and fine results had been obtained.1), 2)

But difficulty exists in manipulation of this device. So the authors improved some parts of the device. Present paper describs the principle of this device and results of its improvements.

1. Introduction

Measurements of the head loss produced by the flow of air in tunnels are being tried in several ways as follows:

1) When the air current is horizontal, the head loss between two points in the tunnel is given by the difference between the both absolute pressures. But when the air current is not horizontal strictly, the pressure due to the weight of air column must be taken away from the difference in the absolute pressure.

2) When pwo points are not so far apart each other, head loss between them can be determined directly by using a U-shaped tube manometer. The U-shaped tube is connected with two rubber tubes which are led to the above twe points respectively. When it is required to determine the head loss between two points which are several kilometers apart, the distance between them is divided into some parts, and the

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head loss between neighbouring two points is measured in the way above mentioned. Total head loss is given by the sum of each head loss.

The former method has the distinct advantage such as a head loss between two points far apart each other can be determined by only measuring the pressure at two points, though in this case it is necessary to know the height difference between two points previously.

In order to rapidly determine the head loss in a magnificent under-ground, the above method is convenient. If an Aneroid barometer is used for this purpose, sufficient accuracy is not obtained. Another device for this purpose was recently developed in France[3], but this is a large size. One of the authors, therefore, has been carried out the study of measuring method with a high accuracy, and has published a device of a new idea. This paper presents the principle of this device and the results of its futher improvement.

2. Principle of measuring method

A principal part of this device is an enclosure which is held in constant temperature and pressure. The temperature of this enclosure is regulated at 0°C with crushed ice. The difference between that constant pressure (called the reference pressure) and the external pressure (atmospheric pressure) is measured by a U-shaped manometer. Difference of pressure between two points is determined from the difference between the readings of this U-shaped manometer obtained at the two points.

When the tunnel is vertical or inclined, following calculations should be employed. The pressure measured by the device, the mean air velocity, the specific weight of air, and the height difference between two poits are represented as p, w, γ, and z respectively. The simbols with suffix 1 or 2 represent the values at the point 1 or 2 in the tunnel. The head loss h_{1-2} between the point 1 and 2 is given by the following equation:

$$h_{1-2} = P_1 - P_2 + \int_2^1 \gamma dz + \frac{1}{g}\int_2^1 \gamma w dw \qquad (1)$$

In practical use,

$$\int_2^1 \gamma dz \doteqdot \frac{1}{2}(\gamma_1 + \gamma_2)(z_1 - z_2) \qquad (2)$$

$$\frac{1}{g}\int_2^1 \gamma w dw \doteqdot \frac{1}{4g}(\gamma_1 + \gamma_2)(w_1^2 - w_2^2) \qquad (3)$$

and γ is represented by

$$\gamma = 0.475\frac{p}{T} - 0.176\frac{p_w}{T} \qquad (4)$$

where p_w, T and p are vapour pressure (mmHg), temperature (K), and atmospheric pressure (mmHg) respectively. The value of p_w is obtained from dry valve temperature, the wet valve temperature and the atmospheric pressure. If the thermometer of wet valve is mounted in the air current with air velocity about 2 m/s, p_w is represented by the following Sprung's equation:

$$p_w = p_s - 0.5(t-t')\frac{p}{760}$$

where t and t' are dry valve temperature (C°) and wet valve temerature (C°), and p_s is a saturated vapour pressure corresponding to the t'.

3. On the design of measuring device

The temperature of the enclosure should be kept constant strictly. If p is the pressure of the air in the enclosure, v is the specific volume and T is the temperature,

$$pv=RT \quad (v=\text{constant}).$$

This equation reduces to

$$dp=\gamma RdT$$

For example, the variation of temperature 0.01°C brings us pressure variation 0.35 mmAq. It is, therefore, required that the temperature in the enclosure should be kept constant within the range of the order of 0.01°C. Though some trials were attempted for this purpose, lastly we got the satisfying results by using a special shaped glass enclosure buried in crushed ice. A vacuum bottle is filled with the crushed ice. Dissolved ice is sucked out of the bottle. If a U-tube is connected to the enclosure directly as Fig.1, in order to compare the pressure in the enclosure with atmospheric pressure, the error affected by the water column moving in the U-tube must be corrected by theoretical calculation. But it is difficult to correct the error at the practical use, because the isothermal change of the air is occured in the enclosure by water moving in the U-tube. Additionaly the temperature of the air in a lead pipe between

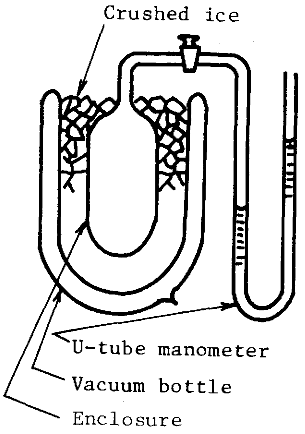

Fig.1 Principle of device

the enclosure and the U-tube is not constant.

One of the authors, therefore, already have carried out the researches on the measuring device which needs no corrections for the water moving in the U-tube. As the results, measuring device as shown in Fig.2 is obtained.

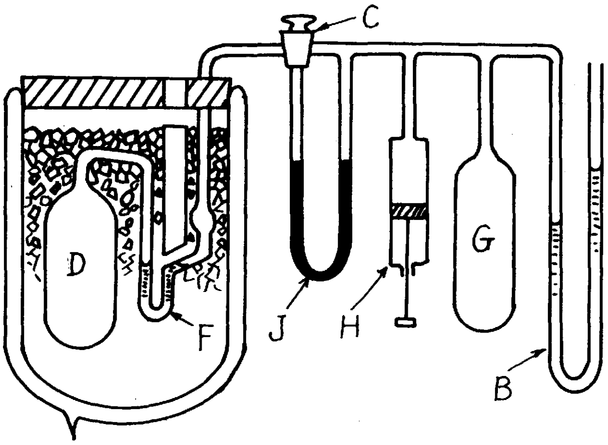

Fig.2 Earlier measuring device

In this figure, D and B are an enclosure and a U-tube respectively, and auxiliary enclosure G, pump H, three way cock C, merculy gauge J, and special U-tube F are put between D and B. The pressure in G is smoothly changeable with the pump H. After the pressure inside G is just equalized to the pressure inside D by manipulating that pump H, the difference between G and atmospheric pressure is measured by the U-tube B. The U-tube F is a special shaped inclined manometer. F and D are assembled into one. The special U-tube F is used only for nulling of the pressure difference between both sides. The cock C is closed all the time except in the case of measurement. At the time of measurement, the cock C is opened, and G, F, and D are connected, in order to equalize the pressure G to the pressure D. The pressure G is equalized to D by adjusting the pump H. If the pressure difference between D and G are so large, the cock C is turned, such as J is connected to F and G. So the pressure G is nearly equalized to the D by means of pump H while observing the U-tube J.

4. Futher improvement of measuring device

As for the device above mentioned, F and D are assembled into one, and buried in a batch of crushed ice. The U-tube F is illuminated by a small light bulb so that the meniscus in U-tube can be observed through a peeping pipe which has proved through the ice. If the pressure difference between D and G are so large, the meniscus of F is beyond the field of vision and liquid overflows from F.

In order to avoid these troubles, diaphragm type pressure sensor is adopted instead of the U-tube F. Application of pressure difference between both sides of the thin diaphragm causes the diaphragm deflection and this deflection causes switching action of electrical circuit (Fig.3). When the pressure difference between D and G is equalized by using the pump H, electrical contact point on the diaphragm is opened, and this is detected by an ammeter. For accurate measurements, diaphragm must be soft and thin. Simple experiments for investigations of relations between diaphragm deflection and pressure are tried on thin rubber film (0.02 mm thickness) and polivinylidenchloride film, usualy called Saranwrappings. These are shown in Fig.4. From the results, rubber film is suitable materials for this purpose.

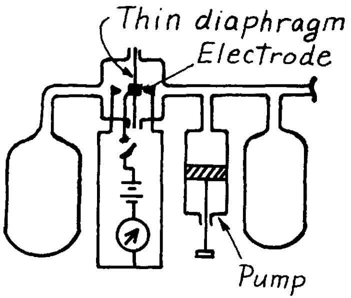

Fig.3 Device fitted with diaphragm sensor

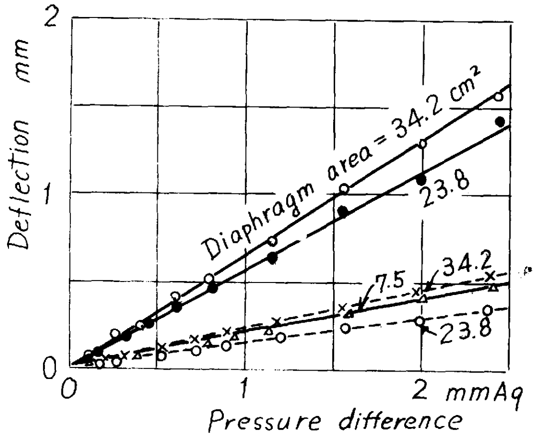

Fig.4 Diaphragm deflection against pressure difference

Solid line: Rubber film

Broken line: Polyvinylidenechloride film

In practice, diaphragm is placed between D and G as in Fig.3. Consequently, deflection of the diaphragm itself causes a compression or expansion of air in the encrosure D. So that the diaphragm deflection depends on the capacity of enclosure D and the area of diaphragm. For instance, if a pressure difference is given, diaphragm deflection is in proportion to the diaphragm area. Larger size diaphragm, however, causes more increase of the pressure in encrosure D. So larger size diaphragm does not necessarily have heigher accuracy. Therefore, a size of diaphragm area and capacity of enclosure D, suitable for heigh accuracy, are determined from following considerations:

In Fig.3, it is assumed that the pressure in D and G are P_0 initialy. when the pressure in G increase to P_0+P_1 , it is desirable to obtain largest deflection of the diaphragm. Suppose the diaphragm deflect like a spherical surface, increasing pressure P_x in D is given approximately by

$$P_x = \frac{P_0}{2V_0} A \cdot h \qquad (5)$$

where V_0 , A, and h represent the capacity of D, diaphragm area, and deflection of center of the diaphragm. Relations among h, A, and pressure difference ΔP between D and G are also given by

$$h = k \cdot A \cdot \Delta P \qquad (k : const.) \qquad (6)$$

From the experiment on the rubber diaphragm, relations to Eq.(5) and Eq.(6) are shown in Fig.5. Now,

$$P_1 = P_x + \Delta P$$

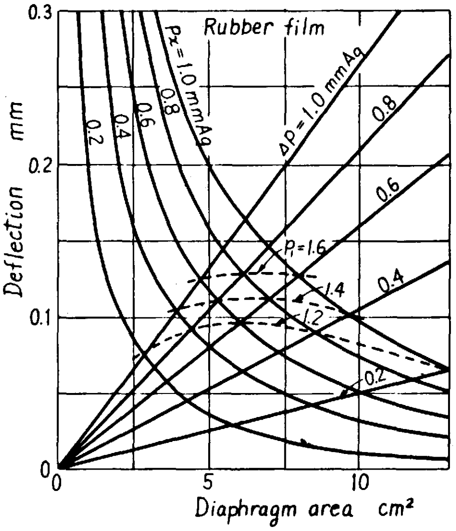

Fig.5 Diagram for estimation of diaphragm area

Hence this device approaches to maximum sensibility, if the size of diaphragm area applies a value at a position of vertex of a curve, broken line in Fig.5. For example, when pressure of G increases by 1.2 mmAq from P_0 , size of the diaphragm area with 6 cm^2 gives a maximum sensibility of this device.

Relations between diaphragm area A and its deflection are shown in Fig.6. From those figures it is evident that the diaphragm deflection h increases with increasing the volume of enclosure V_0 . Muximum deflection of the diaphragm is obtained, when V_0=500cc and diaphragm area is 6 cm^2 practically.

Construction of a diaphragm sensor is shown in Fig.7. In this figure, diaphragm is stretched across a casing and two electrodes are respectively attached on the centers of both sides of the diaphragm. The other electrodes (contact points) are set face to face with that each electrode on the diaphragm. These contact points are able to adjust the distance of themselves with screws.

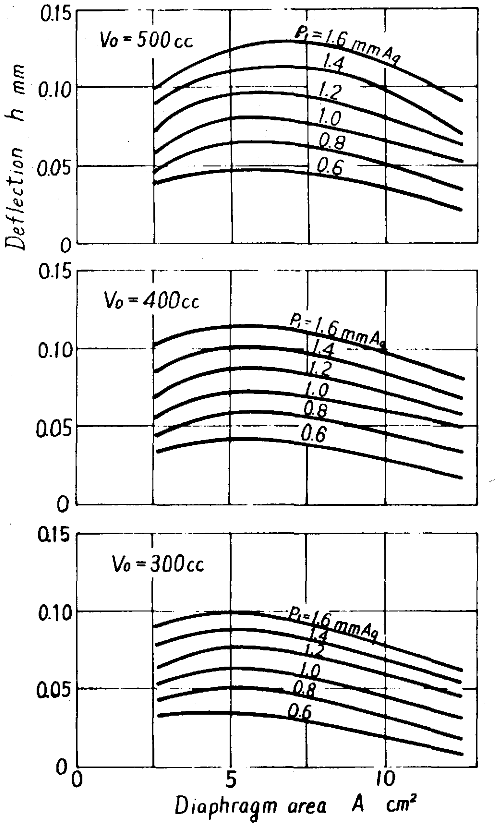

Fig.6 Relations between diaphragm deflection and its area

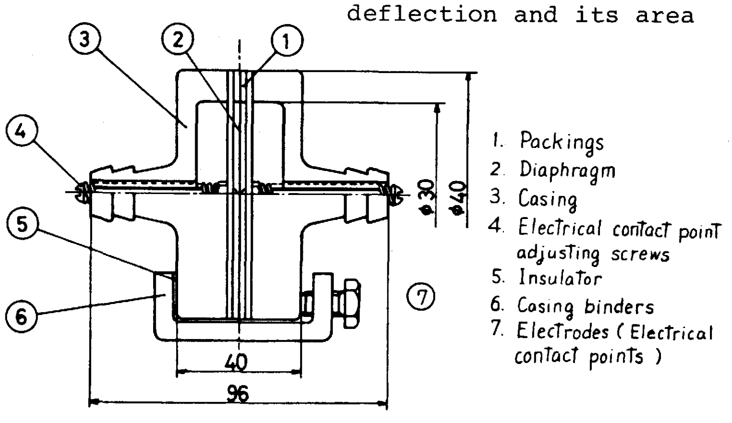

Fig.7 Semi-cross-sectional view of diaphragm sensor

5. Accuracy of device

Fig.8 shows an improved measuring device and its caliblation device. In this figure, the measuring device is enclosed by a broken line. Manipulation of the measuring device is as follows: First of all, enclosure D is buried in crushed ice with a pressure sensor J. After about one hour, air in the enclosure D is cooled at 0 °C, and then the pressure in D is held constant. Secondary, the pressure in G is equalized to the pressure in D by using the pump H. This equality is detected by nulling an ammeter. At this time, reading of U-tube B represents the pressure difference between

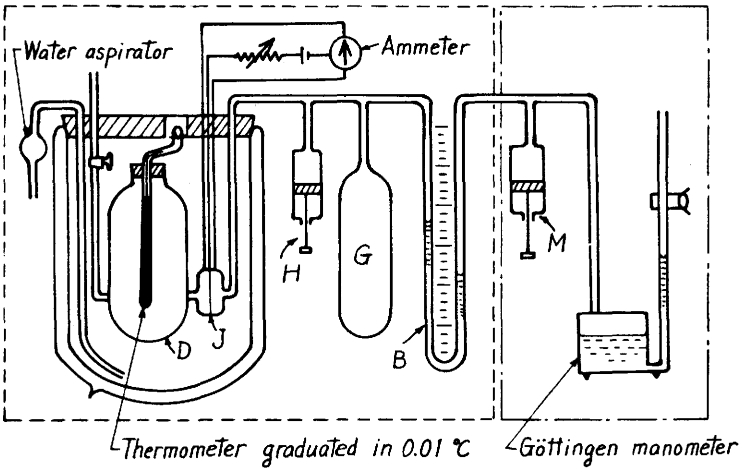

Fig.8 Improved measuring device

D (standerd pressure P_0) and atmospheric pressure.

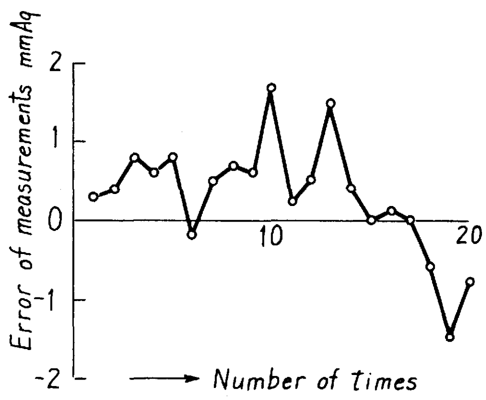

Fig.9 Results of improved measuring device examinations

For an examination of this device, the pressure has been measured at several points whose height levels are known. In this paper, examination device is illustrated in the part enclosed with dot-dash-line in Fig.8. The examinations are tried against several pressures which are operated with pump M. The results obtained are shown in Fig.9. The measurements of 20 times are tried, and it was found that the error of the measurements are less than ±1 mmAq except for a few measurements.

6. Conclusion

The authors had studied the measuring device of tunnel head loss. This device was not to measure the atmospheric pressure directly, but to measure the pressure difference between atmospheric pressure and pressure of the air confined in a enclosure of constant temperature and volume. But this method was difficult to manipulate the device, because the pressure difference was detected with special U-shaped manometer. Such a difficulty is conquered by using a diaphragm sensor instead of the U-shaped manometer. As the diaphragm sensor is used for this device, its advantages are ease of use and faster manipulation, but sensibility of the device is somewhat decreasing. As the results of examination of the device, its measuring error is within of the order of ±1 mmAq.

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