

Time Constant of a Monoplane Wind Vane of Which the Moment of Inertia and Arm Length Are Systematically Changed

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Abstract

Eight monoplane wind vane combinations with two arm lengths and four vane weights are tested in a wind tunnel concerning their time constants of performed damped oscillation in the tunnel air current. The time constants are investigated with respect to the arm length and moment of inertia, the vane form being kept constant. The tested air current speed ranges from 5 to 20 m/s.

1. Objective of the experiment

The leading factors that determine the performance of a wind vane are, besides the vane form, its arm length and moment of inertia. Hitherto the writers conducted several experiments to investigate the vane form (SANUKI, KIMURA and TOYAMA, 1956) where the effect of the arm length and moment of inertia is considered implicitly to be subject to the simple theory described as follows.

The time constant of the damped oscillation of a wind vane in an air current is here defined as the time interval necessary for the curve touching the successive amplitudes to diminish until $1/e$ of its initial value. A simple analysis gives the values of the logarithmic decrement A , the period T and thus defined time constant τ respectively as

$$A = \frac{\pi c}{2\sqrt{Ic'}}$$

$$T = 2\pi\sqrt{\frac{I}{c'}}$$

$$\tau = \frac{T}{2A} = \frac{2I}{c}$$

where

$$c = \frac{1}{2}c_r \rho FVR^2,$$

$$c' = \frac{1}{2} c_r \rho F V^2 R,$$

with c_r = the slope of normal air force coefficient of the vane with respect to its angle of attack, i. e. the angle between the resultant air-flow direction and the vane, ρ = the air density, F = the vane area, V = the air-current speed, R = the arm length between the vane rotation axis and the center of pressure of the vane, and I = the moment of inertia of the oscillating system.

The time constant thus obtained may well be regarded to represent the dynamic performance of a wind vane.

The writers are now in a position, in order to extend their experimental results, to check the above simple relationships by experiments.

2. The test set-up

The test set-up is composed of two types as illustrated in Fig. 1, viz. one with shorter arm and the other with longer arm. To obtain the widest possible range of moment of inertia each vane is constructed in a different way from the others. One construction employs a thin vinyl cloth spread within a thin frame work of 1 mm diameter aluminium wire weighing only 20 gr in total. The other constructions are composed of 1 mm thick aluminium sheet or sheets laminated two- or threefold. A single aluminium sheet weighs 83 gr.

The form of all the vane constructions is precisely the same except a minor difference in thickness and in the shape of the frontal count-balance to balance the vane. Thus the smallest moment of inertia of the oscillating system is effected for the vinyl vane with a shorter arm as 58 gr cm^2 and the largest for the three-ply aluminium vane with longer arm as 949 gr cm^2 , a range almost 1:20 being realised.

The experiment is conducted in the wind tunnel for each vane to perform a damped oscillation from an initial deviation of 60° to 80° from the tunnel air-current. The mode of oscillation is recorded on an electromagnetic oscillograph by means of a sliding shoe attached to the vane boss and a circular resistor fixed on the vertical supporting shaft. Wind speed is varied in four steps, viz. 5, 10, 15 and 20 m/s approximately.

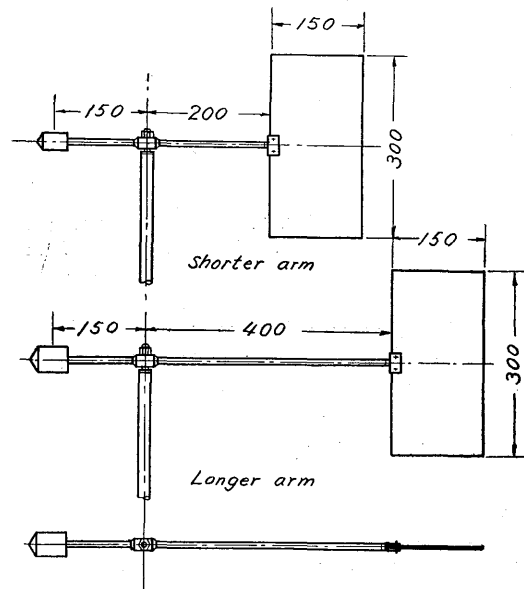


Fig. 1. Tested monoplane wind vanes.

3. Experimental results

The time constant is read off from the curve drawn in the time-amplitude coordinates based on the oscillograph record. Each time constant τ is multiplied by the relevant wind speed V to be free from the effect of the latter, as can be seen from the above equations.

The results are illustrated against the moment of inertia I in Fig. 2 with the arm length of the vane as parameter. In the figure a theoretical curve (broken line) is drawn, which is obtained for the shorter arm by correcting the arm length. Here the arm length is taken as the nominal length of 200 or 400 mm plus the quarter-chord length of the vane, viz. 37.5 mm. Thus the curve for the longer arm shifted vertically by increasing its ordinate by a factor $(437.5/237.5)^2 = 3.38$ according to the above equations. The correction may be effected for the longer arm from the shorter one, but the present practice will probably be more reasonable, as the longer arm might well be subject to the assumptions made at the deduction of the equations.

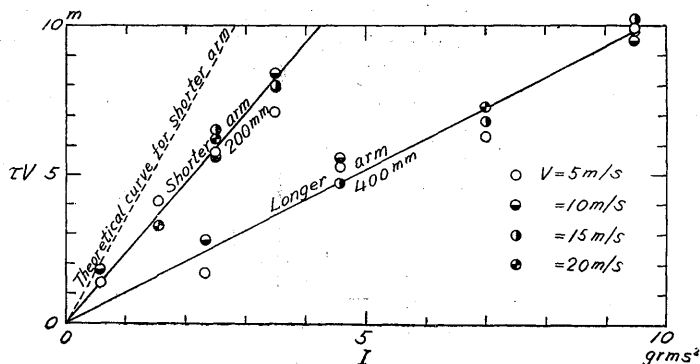


Fig. 2. Time constant τ multiplied by wind speed V against moment of inertia I with parameter of nominal arm length (M.R.I. Wind tunnel).

It is remarked first that the values of τV are practically free from the effect of the wind speed considering the magnitude of errors involved in the evaluation of τ .

The most conspicuous thing is the linearity of τV curves which confirms the above equations. The correction of the arm length is not so consistent with the theory.

Anyhow a range of nearly 1:10 for the time constant is seen here to be obtainable by reducing the moment of inertia by 1:20. The fact might be of some use for the actual design.

4. Conclusions

- 1) The time constant is inversely proportional to the wind speed.
- 2) If the wind speed is constant the time constant is proportional to the moment of inertia.

3) The shorter arm affords a smaller time constant than the theory. This fact is in favour of the shorter arm but an optimum arm length can exist as the static sensitivity of a vane is proportional to it.

References

- SANUKI, M., S. KIMURA, and S. TOYAMA, 1956: The time constants of biplane wind vanes, Pap. Met. Geophys. 6, p. 244-246.
- SANUKI, M., S. KIMURA, and S. TOYAMA, 1956: The time constants of biplane wind vanes (II), Pap. Met. Geophys. 7, p. 123-127.

慣性能率及び腕長を系統的に変えた単葉風向計の時定数

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腕長を2種, 風板重量及び釣合錘を4種変えた合計8種類の単葉風向計を, 気象研究所1.5m風洞で実験し時定数を求めた。この振動系の慣性能率は約1:20の範囲にわたるので通常使用される風向計を広範囲系統的に実験したものといつてよいであろう。実験風速は5~20 m/sでこれも常用範囲をカバーする。

結果として

- 1) 時定数は風速に逆比例する。
- 2) 風速一定ならば, 時定数は振動系の慣性能率に比例する。
- 3) 短い腕長は長い腕長よりも, 簡単な理論から推定される時定数の傾向にくらべて小さい時定数を与える。これは短い腕長に有利な結果であつて, その理由は非定常的な空気流の特性その他によるものと思われる。しかし短い腕長は静的特性が悪いから, 動的特性と合せて考えるとき適当な腕長が存在するであろう。