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Calibration and application of high torques to a reaction air turbine viscometer

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A reaction air turbine viscometer has been calibrated with the air bearing placed both horizontally and vertically. It has been shown that changing the position of the bearing varied the result by less than 2%. The air bearing pulley employed in the calibration is described; this may also be used to apply high torques during a rheological analysis.

Warburton & Barry (1968) have described a concentric cylinder creep viscometer in which an air bearing was used to centre, and a berilium-copper wire was used to support, the inner cylinder. The torque was applied either by weights hanging over pulleys, or from a modification of a chemical balance.

Davis, Deer & Warburton (1968) improved the viscometer by using a P.C.B.1 Westwind air turbine in which bearing air was used to centre and support the inner cylinder, and turbine air was used to apply the torque. They calibrated the applied turbine pressure in terms of torque at a constant bearing pressure of 2080 torr (approximately 39 p.s.i.) by attaching at 1 cm radius bobbin to the end of the spindle of the turbine rotor, and, with the bearing horizontal, they applied weights directly. They found a linear relation between turbine pressure and torque over a pressure range of 100–2000 torr, with a constant difference of 33 torr between the turbine pressures at which upward and downward movement of the weight just occurred. This difference was attributed to standing friction in the bearing.

To overcome the problem of this residual friction, and to extend the range of the viscometer to lower torques, the P.C.B.I. turbine was replaced by an improved air turbine, the Westwind P.C.B.III, which has been described by Davis (1969). He calibrated the P.C.B.III for low torques by the method described above, keeping the bearing pressure constant at 120 torr (approximately 2·25 p.s.i.). Again there was a linear relation between turbine pressure in the range 0–100 torr, and torque. The standing friction in the bearing was reduced to the equivalent of 3 torr turbine pressure. On increasing the bearing pressure gradually from 50 to 250 torr, Davis found the turbine pressure required to counteract a constant torque (5 g cm) increased, that is, the torque produced by the turbine pressure was reduced. Doubling the standard bearing pressure of 120 torr caused a 3% change in turbine calibration.

We have constructed a similar viscometer using the Westwind P.C.B.III. The applied turbine pressure was calibrated in terms of torque over a wide range of torques (50–16,000 dyne cm), with the bearing horizontal, by a similar method to that of Davis & others (1968). On computer analysis of the results of eight complete calibrations with a constant bearing pressure of 40 p.s.i. an excellent linear relation was found between turbine pressure and torque over the pressure range 5–370 torr (the resultant calibration graph had a regression coefficient of 0·9997 and a gradient of 43·3 dyne cm

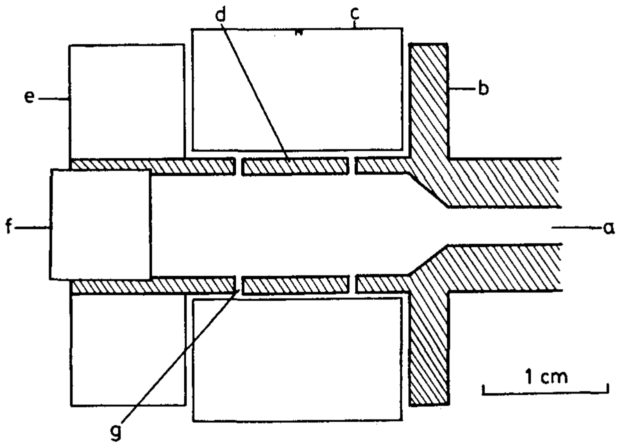

FIG. 1. Sectional diagram of brass air bearing pulley. Key: a. compressed air. b. Inner thrust collar. c. Rotor. d. Journal. e. Outer thrust collar. f. Taper screw. g. Journal air hole. For clarity, the thrust and bearing air gaps and the journal holes are not to scale.

torr^{-1}). The graph however did not pass through the origin, but computer extrapolation gave an intercept of 1·26 torr, which is similar to that found by Davis (1969). This value is also attributed to a small standing friction in the bearing. On repeating the calibration for bearing pressures 25, 30, 35, 40, 50 and 80 p.s.i., the calibration parameters did not change within the limits of experimental error.

The air bearing is placed vertically when used as part of the viscometer, and supports the weight of the inner cylinder assembly. As the distribution of air, and hence the standing friction in the bearing may possibly vary with position, we considered it important to check the calibration with the bearing vertical, and the inner cylinder and the transducer arm in place. In the vertical position, weights cannot be applied directly to the turbine rotor, and so a second air bearing was constructed to function as a frictionless pulley wheel (Fig. 1).

The air pulley is inexpensive, robust and simple to manufacture. The journal has two sets of six holes drilled radially, through which air (at about 30 p.s.i.) passes to the bearing faces. Manufacture is simplified as air at the thrust faces is leakage bearing air, which is sufficient to centre the rotor and thrust holes are not required. The air gap between the journal and the rotor is approximately 0·001 inch (this is not critical) and the thrust air gap can be adjusted and maintained by a taper screw, which expands against the shaft to hold the outer thrust collar firmly in place. The pulley is essentially frictionless. For example, it could be made to rotate for a long time in either direction by giving the rotor an initial spin. There was a slight tendency for it to rotate preferentially in one direction, i.e. to "windmill". This is a common effect in air bearings due, in this case, to the air holes not being drilled absolutely radially. However, during the calibration the weights were hung both in the direction of the windmill effect and against it, and no difference in response was found.

Computer analysis of the results of eight complete calibrations in the vertical position again showed an excellent linear relation between turbine pressure and torque over a turbine pressure range 27–300 torr (regression coefficient 0·9997, gradient 44·1 dyne cm torr^{-1}, intercept 1·38 torr). Typical results for the horizontal and vertical positions are shown in Fig. 2.

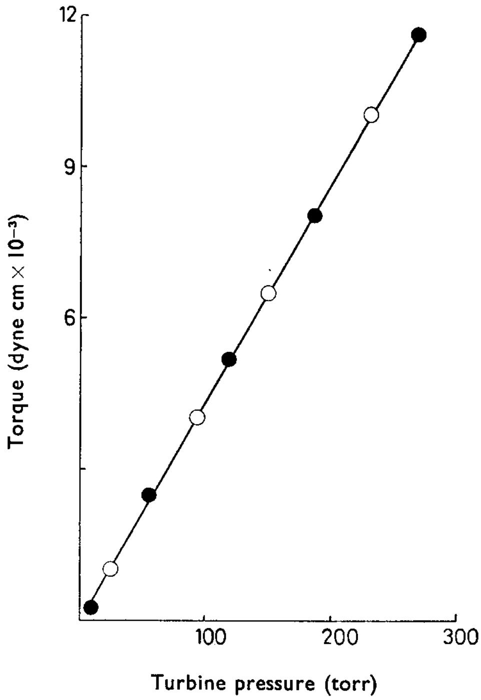

FIG. 2. Representative data from the calibration of the reaction air turbine. –●– bearing in the horizontal position, –○– bearing in the vertical position. Single calibration line drawn through both sets of data.

As the gradients for the graphs differed by less than 2% (which we attribute to alteration in the distribution of air), it was concluded that movement of the bearing from the horizontal to the vertical position did not *markedly* alter the calibration. However, although less than 2% variation may be satisfactory for many uses of the instrument, in particular when used as a creep viscometer, for more precise work, for example when used as a rotational viscometer, we consider that the bearing should be calibrated in the final working position.

The air pulley is also useful for applying a torque directly during a test if forces in excess of those available from the laboratory air supply are required.

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