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A Sensitive Torque Meter for Wind-Tunnel Applications

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A REQUIREMENT to measure the rolling moment on a small wing in a wind tunnel has led to the development of a simple yet highly sensitive torque meter. With a span of 6.6 cm (2.6 in.) and a freestream velocity of 14 m/sec (45 ft/sec) the magnitude of the expected rolling moment on this wing was estimated to be a maximum of only 10 gm-cm (0.14 oz-in.). This low torque level and the size of the wind-tunnel test section, 30.5×30.5 cm (1ft×1ft), resulted in the need for a compact instrument that could resolve torques of the order of 1 gm-cm (0.014 oz-in.) or less. Simplicity and economy of construction also were desired. Several concepts were considered, including strain gage load cells, reflected light beams, and servo-driven null systems. However, none was found which met the combined requirements.

A satisfactory device finally was developed which did meet the requirements, and also was insensitive to bending moments and axial and radial loads. The instrument, shown in Fig. 1, incorporates a central element mounted on springs of the flexural pivot type within a fixed tubular case. When torque is applied, a slight rotation is allowed which is sensed by a rotary variable differential transformer (RVDT). In a size suited to this application (0.48-cm, 3/16-in. o.d.) the flexural pivots, manufactured by the Bendix Corporation, are available with torsional spring rates as low as 0.8 gm-cm/deg (0.011 oz-in./deg). Manufacturer's data show that their response to torsion is virtually unaffected by radial and axial loads of the magnitudes anticipated. The RVDT is made by Pickering and Co. (Model No. 21300) and has separate rotor and stator sections. In combination with the flexural pivots, the action of the instrument is frictionless. In principle, the resolution is limited only by the means used to detect the output of the RVDT. As shown in the drawing, the frontal area (3.81-cm, 1.5-in., diam) is limited mainly by the size of the RVDT, which, in this case, is the smallest available of the desired type. The design easily is adapted to RVDT's of smaller diameter should they be available. For extremely small size, the RVDT could be made an integral part of the instrument.

Figure 2 shows how the parts are assembled to allow the desired response. The spiders, which support the forward end of each flexural pivot, are fixed to the outer case by the clamping action of the jam nut against the spacer tubes and the stop ring (also see Fig. 1). The aft ends of the flexural pivots are inserted in holes in the two aft-most pieces of the three-piece rotor, where they are held by set screws. The cutouts in the rotor pieces allow the legs of the spiders to extend to the outer case and provide for the limited rotation of

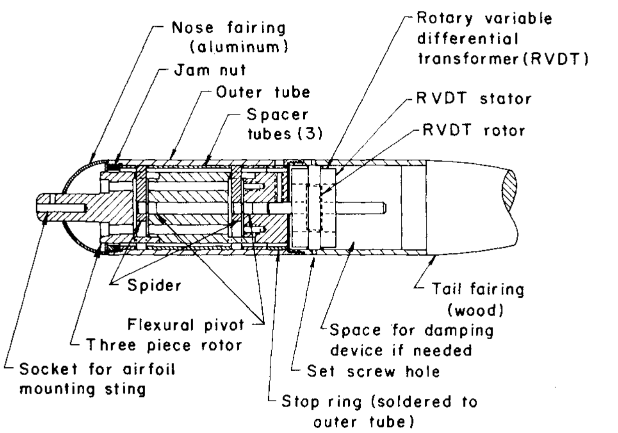

Fig. 1 Longitudinal cross section of torque meter. All parts are stainless steel unless noted.

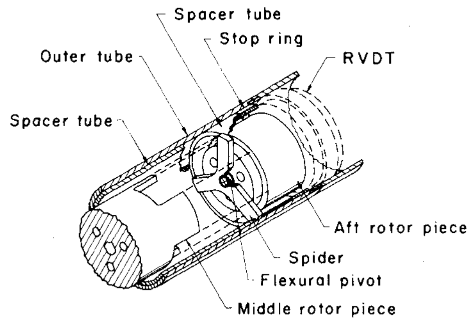

Fig. 2 Cut-away view showing assembly of flexural pivot and related parts.

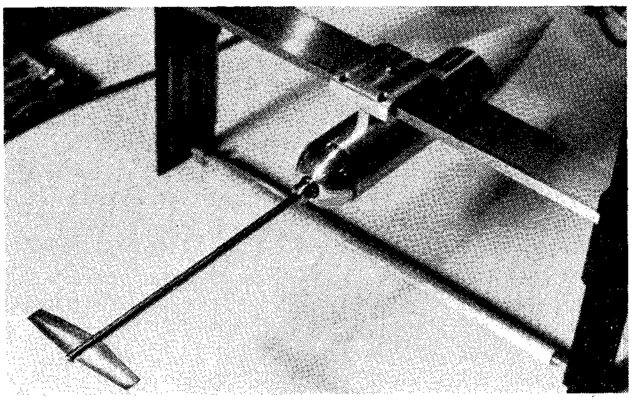

Fig. 3 Torque meter with wing model mounted in traversing mechanism.

the rotor in response to applied torque. In Fig. 3, the torque meter is shown mounted in a traversing mechanism outside the tunnel.

The amount of rotation is controlled through the choice of the flexural pivot spring rate. For the rolling moment measurements, it was desired to minimize the rotation so that the wing attitude could be considered fixed. At the same time the motion had to be sufficient to produce a measurable response by the RVDT. Some typical data will illustrate the characteristics of the instrument.

The flexural pivots each had a torsional spring rate of 6.56 gm-cm/deg (0.091 oz-in./deg) (Bendix Cat. No. 5006-600). Thus, the two in combination gave an instrument spring rate of 13.1 gm-cm/deg (0.18 oz-in./deg) or a rotary sensitivity of 0.076 deg/gm-cm (5.5 deg/oz-in.). The RVDT was excited by a 10 kHz signal of 3 Vrms amplitude, and the output was demodulated through a diode circuit having a zero adjustment

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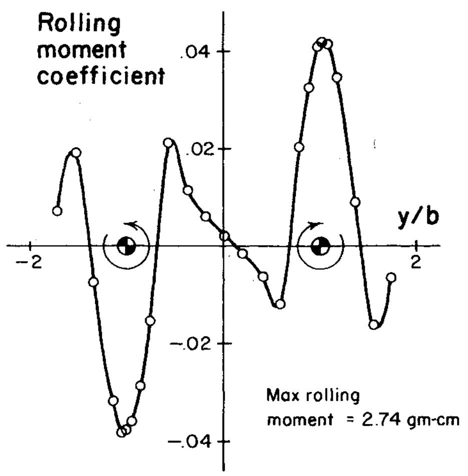

Fig. 4 Example of rolling moment data obtained with torque meter and model wing. The wing was traversed through a pair of counter-rotating line vortices located at $y/b = \pm 1$, where y is the lateral distance and b is the span of the model wing.

potentiometer. The output was measured on a digital dc voltmeter on the ±0.1 V full-scale range. The meter resolution was 0.01 mV.

The instrument was calibrated by hanging weights on the ends of the model wing. The calibration was found to be linear within about 1% throughout the ±5-deg range of allowable deflection. The value of the calibration factor was 3.85 mV/gm-cm (277 mV/oz-in.). Thus, the maximum expected rolling moment of 10 gm-cm (0.14 oz-in.) would produce a response of 38.5 mV with an angular deflection of only 0.76 deg. These characteristics were considered quite satisfactory. In fact, when the rolling moment measurements were made, the maximum values were found to be less than 3 gm-cm (0.04 oz-in.), so that the resulting angular deflections were in the neighborhood of 0.2 deg. For a voltmeter resolution of 0.01 mV, the torsional resolution of the torque meter is about 0.0003 gm-cm (3.6×10^{-6} oz-in.), with an angular resolution of 2×10^{-4} deg or 0.7 sec of arc. Of course, the latter figure is attributable to the RVDT itself and only depends on the torque meter design insofar as the alignment of its stator and rotor are concerned. If the more sensitive flexural pivots of the same size were to be used—with a combined sensitivity of 1.6 gm-cm/deg—the foregoing resolutions could be improved by a factor of 8.2.

One aspect of the design which could have proved troublesome is the lack of self-contained means of damping unwanted oscillations. For the rolling moment measurements, however, it was found that the aerodynamic damping of the wing model itself effectively reduced the amplitude of oscillations to an acceptable level. In anticipation of such a problem, the torque meter rotor was made as massive as possible to keep its undamped natural frequency as low as possible. This frequency turned out to be about 16 Hz, and it was a simple matter to make the time constant of the demodulation circuit short enough so that frequencies in this range had no measurable effect on the dc output. Viscous or eddy current damping devices could be added if necessary, however, and a space at the aft end of the instrument was provided for that purpose.

To illustrate the performance of the torque meter in the measurement of rolling moment, some typical data are shown in Fig. 4. The data show rolling moment coefficient of the wing model as it is traversed laterally through the center lines of a pair of counter-rotating parallel line vortices. The vortices are spaced apart a distance equal to twice the span of the model wing. They represent the adjacent tip vortices from two aircraft flying side by side so that a region of strong upwash is produced between them. The data are taken from Ref. 1. The torque meter proved to be extremely reliable and simple to use, and the resulting data were both repeatable and consistent with expected trends.

Although nominally designed for use in measuring torque, the instrument can be used, through modification of the wing mounting system, to measure the wing lift curve. To accomplish this, a crossarm is mounted at the end of the sting. The wing is fixed at one end of the arm with a means for adjusting angle of attack, and a counterweight is mounted at the other end. This arrangement was quite useful, although the aerodynamic damping of oscillations was not very effective as the wing approached stall.

Another possible use for this device would be as a nonrotating vorticity meter. For such an application, the instrument would function in the same way as it does when measuring rolling moment. For improved spatial resolution, however, the wing would be replaced by flat vanes of a size small enough to resolve vorticity gradients in the flow. The possibility of making a practical vorticity meter using this basic design is being investigated.

Acknowledgment

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Aerodynamic Stability of Tethered Bodies

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Nomenclature

$OXYZ$	= fixed or inertial coordinate system
$O'X'Y'Z'$	= fixed body or moving coordinate system
X,Y,Z	= coordinates of a point with respect to $OXYZ$
s	= running distance along the cable measured from 0
σ	= complex frequency of Laplace transformation
ρ	= density of air
ρ_c	= mass per unit length of the cable
γ	= angle between an element of the cable and OYZ plane such that $\cos^2\gamma = (Y^2{}_s + Z^2{}_s)$

Subscripts

o	= the equilibrium configuration
o'	= the property at O' with respect to O
s	= differentiation with respect to s
c	= the condition at the confluence point C in Fig. 1 and is placed before other subscripts

The rest of the symbols are standard and essentially the same as those in Ref. 1.

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