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A Sensitive Rolling Moment Balance for Use in Supersonic Blowdown Tunnels

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Introduction

A STRAIN-GAGE balance is a standard device for measurement of aerodynamic loads acting on models in a wind tunnel. The most common type—the six component internal balance—is employed for general, routine testing while special-purpose balances designed to meet exclusive requirements are used for specialized tests. Design of balances meant for use in supersonic blowdown tunnels can often be complicated on account of the need to withstand large transient loads that occur on the models during tunnel starting and stopping and yet have adequate sensitivity. These problems become particularly severe when the loads to be measured are of low magnitude, such as in some special tests. Successful solutions to these problems are often obtained by adoption of some unconventional design concepts and schemes. A recent example of a novel scheme for measurement of low rolling moments in low speed wind tunnels is found in Ref. 1.

A special-purpose internal strain-gage balance was developed to measure low rolling moments in a trisonic blowdown tunnel. The capability of the balance to withstand large magnitudes of all the six components of load while retaining a high sensitivity to rolling moment is an important and special feature. The balance was required to measure maximum rolling moments varying between 0.2 and 10 kg-cm with a resolution of 0.002 kg-cm on wing-body models of 36 mm diameter and 380 mm length. The tunnel starting/stopping loads that the balance had to withstand were large owing not only to the relatively large size of models but also to the high pressure ratios required for starting the tunnel (starting pressures at Mach 2.5 and 3 were 5 and 6.5 atm, respectively). The above combined requirements could not be met by the usual balance arrangements employing cruciform or torque tube element and a balance incorporating some unusual design features, described below, was developed.

Description

The balance is of floating-frame type and the sensing element is essentially a crossed-flexure pivot formed by four strips connecting the outer sleeve to the inner rod (Fig. 1). The strips are arranged in pairs in two transverse planes and the distance between the strips in each plane is kept as large as possible to resist high pitching and yawing moments. The strips, made of heat treated high strength alloy steel, are 1 mm thick by 9 mm wide and provide adequate sensitivity to low rolling moments. In order to increase the capability of the balance to withstand large rolling moment, an overload safeguard that automatically limits the rolling moment in the strips is provided. The safeguard, Fig. 2, is formed by a stop connected to the outer sleeve and passing through slots in the inner rod. When the balance is subjected to a rolling moment the gap between the stop and the inner rod decreases at two diametrically opposite ends owing to the elastic deflection of the element. This gap is so adjusted that when the rolling moment on the balance equals a predetermined value, the stop makes contact with the inner rod (Fig. 2b) and further rolling moment is directly transmitted from the outer sleeve to the inner rod bypassing the element. The gap was precisely adjusted to the desired value and made uniform on all sides using accurate measurements of slot widths on assembly and appropriately matching the dimensions of the stop by precision machining. By the above arrangement, the rolling moment that the balance can withstand is limited only by the strength of the inner rod and the element strips can be made as thin as required by sensitivity considerations. The maximum combined loads that the balance can withstand are normal force and side force (NF and SF) = 200 kg, axial force (AF) = 30 kg, pitching and yawing moment (PM and YM) = 450 kg-cm, and rolling moment (RM) = 300 kg-cm; about three times the above magnitude can be safely withstood when the loads are acting individually. In order to give an idea of the wide range of capabilities of this type of balance a set of characteristics estimated mainly using the methods of Ref. 2 for a family of balances is noted in Table 1. The overall dimensions of the balances are the same as noted in Figs. 1 and 3 and the thickness of the strips only differ; use of a standard balance material (17-4PH steel) with a design stress of 5802 kg/cm^2 and foil gages with a maximum combined gage stress of 3868 kg/cm^2 has been assumed.

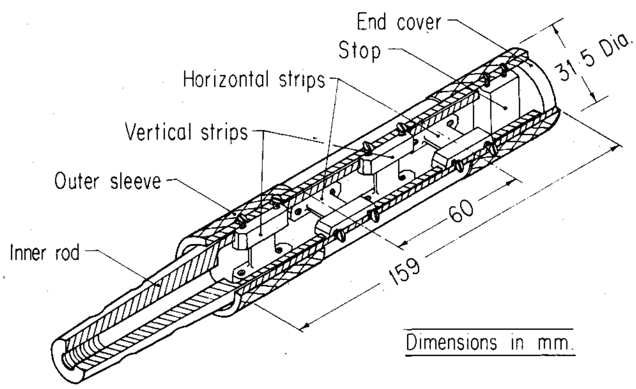

Fig. 1 Cutaway view of the balance assembly.

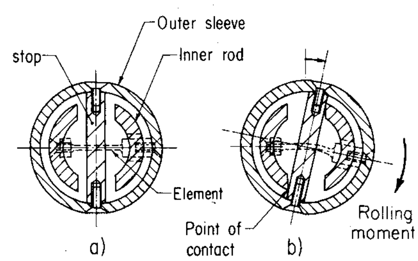

Fig. 2 Schematic showing the working of overload safeguard (only one element shown for clarity): a) rolling moment = 0, b) rolling moment ≥ safe limit for element.

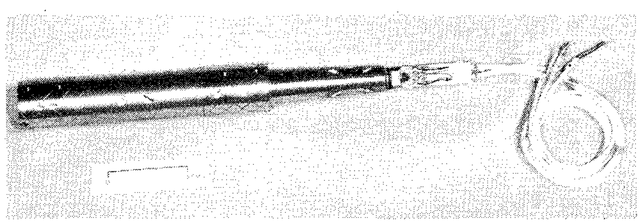

Fig. 3 Photograph of balance with connector.

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Table 1 Estimated characteristics of a family of balances

Thickness of strip, mm	Capacity, kg-cm	Safe maximum loads[a] NF or SF, kg	PM or YM, kg-cm	FSO,[b] mVs	Resolution,[c] kg-cm
0.4	1	186	835	4	0.0003
0.7	5	325	1462	4	0.001
1.0	10	464	2099	4	0.003
2.0	50	928	4177	4	0.01
3.0	100	1392	6266	4	0.03
4.0	200	1956	8354	4	0.05

[a] RM = 1000 kg-cm and AF = 300 kg in all cases; the above loads are for individual loading and the safe combined loads are about one third of these. [b] Full scale output for 4 V excitation. [c] For 1 μV signal resolution.

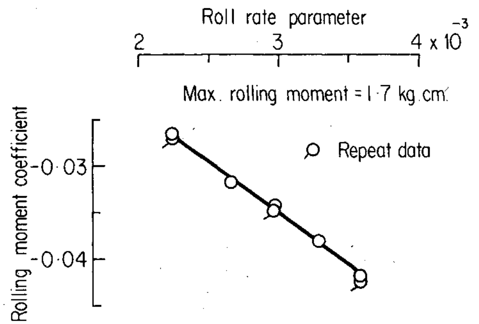

Fig. 4 Typical rolling moment data obtained with the balance at a Mach number of 3.

A four arm bridge formed by KYOWA 1 mm foil strain gages mounted on one of the strips provided the balance output. The balance was calibrated in a rig that had facilities for applying a combined loading of NF (or SF), PM (or YM), AF, and RM. The sensitivity was 0.8 mV/kg-cm for a 4 V excitation and the resolution was limited only by the signal processing equipment. In the present tests, the latter had a resolution of 1 μV giving a rolling moment resolution of 0.0013 kg-cm. Linearity was better than 0.25% and the sensitivity was found invariant in the presence of other loads over the test range of values (NF = 10 kg, AF = 7 kg, and PM = 70 kg-cm). Theoretical estimates[2] show that the change in rolling moment sensitivity is within 1% in the presence of other loads of about twice the magnitude of the test load range.

The balance was used for rolling moment measurements to obtain roll-damping on rotating models[3] at Mach numbers between 0.5 and 3.0 in a trisonic blowdown tunnel. A typical rolling moment plot is shown in Fig. 4. The maximum measured rolling moment was between 0.15 and 9 kg-cm and repeatable data consistent with expected trends were obtained in all the tests. Although ideally suited for application in supersonic blowdown tunnels, this type of balance can in general be used in all situations requiring accurate rolling moment measurement of low magnitudes, even in the presence of other moderately large loads such as in high-incidence testing. Typical applications are measurement of roll control effectiveness and roll-damping derivative.

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