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An elastic element of the forced oscillation apparatus for dynamic wind tunnel measurements

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ABSTRACT

In this paper an elastic element of the forced oscillation apparatus for dynamic measurements in the T-38 wind tunnel is described. The forced oscillation apparatus consists of the elastic element, dynamic balance, actuator arm, hydraulic driving mechanism and sting. The front part of the apparatus is installed into a model during wind tunnel measurements. This element supports large aerodynamic loads and enables primary oscillatory motion of wind tunnel models. It has to enable high compliance in the apparatus primary rotational degree of freedom and high stiffness in the secondary degrees of freedom. The elastic element is formed from a pair of symmetrical cross-flexures with variable cross-section of the strips. The oscillatory motion sensor is realized on the cross-flexures. This sensor provides clean referent signal for data reduction in the dynamic wind tunnel tests.

1. Introduction

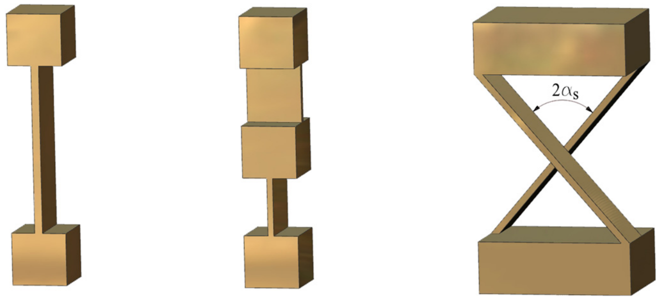

Fig. 1. Flexure pivots.

Flexure pivots are moving parts of sensitive instruments and mechanisms which provide the relative displacement between two adjacent rigid bodies. The most common types of flexure pivots are shown in Fig. 1. The simplest type consists of a thin metal strip which is free to bend. Many combinations of single flexures may be designed and manufactured for different purposes. Very often two of flexure pivots, one at right angle to the other, are machined out of a bar. A special kind of flexure pivot is a cross-flexure pivot. The cross-flexure pivots have been used for many years and in a majority of fields in terms of the good performance. They have a bi-symmetrical geometry and contain two leaf springs of equal dimensions crossing at their midpoints and forming an angle of $2\alpha_s$. For stability, stiffness and ease of construction reasons it is adopted that $2\alpha_s = \pi/2$ [1]. These pivots are commonly used in metrology as dynamometers and in seismometers, in pressure transducers, in the aerospace and motor fields, in optical instrumentation and in gyroscopes. The cross-flexure pivots are used for several applications where particular working conditions, such as high or cryogenic temperatures, aggressive, dirty, ultra clean and radiation environments, do not allow conventional sliding and rolling bearings to be used. In these cases, the mechanical design of pivots involves the evaluation of the leaf springs strength and stiffness as well as a stability analysis of the overall mechanism [2]. Also, these pivots permit a high rotational accuracy to be obtained via compact, reliable and maintenance-free design with limited production costs [3–8].

The cross-flexure pivots are superior to conventional joint in controlling an oscillatory motion. They are perfectly linear since there are no moving parts in contact to produce friction; also their construction enables them to withstand a sudden reversal of load. An additional advantage over a conventional joint lies in the fact that with no moving parts in contact, no lubrication is necessary and no wear takes place. The cross-flexure pivots are characterized by a high compliance with respect to the in-plane rotational degree of freedom and high stiffness in others, secondary, degrees of freedom. These characteristics make them very useful in dynamic wind tunnel experiments with forced oscillation motion. The first

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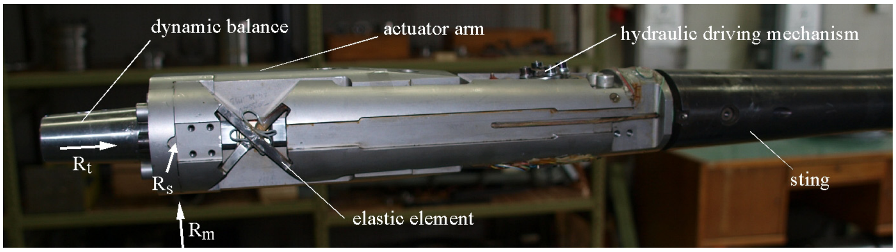

Fig. 2. The front part of the forced oscillation apparatus.

forced oscillation apparatus, with cross-flexure pivot, capable of direct measurement of the full complement of damping, cross and cross-coupling moment derivatives due to pitching or yawing was constructed at NAE wind tunnels in 1973 (National Research Council, Canada). The model is driven electromagnetically by means of a single-turn drive coil that can move in a gap between two permanent magnets, and the balance consists of cruciform flexures in yaw and in roll and a cross-flexure pivot in pitch. In the AEDC VKF wind tunnel the forced oscillation apparatus for measurements of pitch or yaw damping utilizes a cross-flexure pivot, an electric shaker motor and one-component moment beam which is instrumented with strain gauges to measure the forcing moment of the shaker motor. The cross flexures, which are instrumented with strain gauges to provide a voltage proportional to the model pitch displacement, support the model loads and provide a restoring moment which cancels the inertia moment when the system is operating at the natural frequency of the model-flexure system. Several forced oscillation apparatuses are available in AEDC PWT test facilities for use in their 4-Foot and 16-Foot transonic wind tunnels and 16-Foot supersonic wind tunnel. They are designed for high loads and are, therefore, hydraulically driven. Cross-flexure pivots are used on these apparatuses and frequency can be adjusted by interchanging a cantilever spring [9–13]. The forced oscillation apparatus for measurement of pitch or yaw damping derivatives in the T-38 wind tunnel of VTI is apparatus with cross-flexure pivot and with variable cross-section of the strips [14,15]. This pivot enables angular oscillatory motion of the wind tunnel model. The variable cross-section of strips provided significant increase in stiffness of the pivot in the model secondary degrees of freedom.

2. Basic principles of the dynamic experiments in the T-38 wind tunnel

The concept of stability derivatives is related to the traditional form of equations of motion where the result of a small disturbance from the equilibrium flight condition is described by linear superposition of contributions caused by the change in various attitude variables and their time rates to change. In the design of the new aircraft or missile the dynamic derivatives of interests are not limited only to the three damping derivatives (direct damping derivative in pitch, direct damping derivative in yaw and direct damping derivative in roll). Cross and cross-coupling derivatives may be quite important in the design process. Cross and cross-coupling derivatives of interests are: cross derivative of the rolling moment due to yawing, cross derivative of the yawing moment due to rolling, cross-coupling derivatives of the pitching moment due to yawing or rolling and cross-coupling derivative of the yawing moment due to pitching.

The main task of the dynamic experiments in wind tunnels is to obtain model-scale dynamic stability information of the aircrafts at realistic Reynolds and Mach numbers. Various techniques for the dynamic experiments are in use [9,11,16,17]. The forced oscillation techniques are the most often used. In these experiments the oscillatory motion is induced to a wind tunnel model in one (the primary) degree of freedom. The reaction measured in that primary degree of freedom determines direct damping derivative. For the case when model primary motion caused model oscillatory motion in the secondary degrees of freedom, various cross and cross-coupling derivatives can be measured. Such experiments can be performed using either constant oscillatory moment or constant oscillatory displacement. If an electromagnetic drive is used, the amplitude of the excitation moment (or force) is usually constant and the amplitude of the displacement depends on the total damping in the system. If a mechanical or hydraulic drive is used, displacement amplitude is then kept constant and amplitude of the excitation moment (or force) is adjusted as necessary.

The apparatus for the dynamic measurements in the T-38 wind tunnel is a full-model forced oscillation apparatus with primary angular oscillation around the wind tunnel model transversal axis [18,19]. The wind tunnel model is forced to oscillate at constant amplitude. This apparatus is distinguished by the capability to measure aerodynamic reaction in the primary and secondary degrees of freedom. The front part of the apparatus is shown in Fig. 2, where R_t is aerodynamic axial force, R_m is aerodynamic normal force and R_s is aerodynamic side force.

The primary oscillatory motion is imparted to a model by the hydraulic driving mechanism in which piston moves and applies the driving force to the actuator arm. The actuator arm is linked to moving end of the elastic element. The dynamic balance is mounted inside the actuator arm between cross-flexures of the elastic element. This balance is monoblock strain gauge balance, and it is used for the measurements of five components of the aerodynamic load: side force, normal force, rolling moment, pitching moment and yawing moment. Also, excitation moment, as well as secondary reactions cased by model oscillatory motion is measured by the dynamic balance. The hydraulic actuator is controlled by the hydraulic servo-valve located at the apparatus sting base. The model oscillatory motion sensors are realized on the cross-flexures of the elastic element. To obtain the yawing moment derivative due to yawing oscillation the apparatus has to be rotated 90° around its longitudinal axis.

To obtain the direct damping derivative due to model oscillatory motion in pitch the amplitude of the excitation moment, amplitude of the model angular oscillatory motion and phase between these quantities have to be measured. The measurement of stability derivatives using forced oscillation technique cannot be performed directly. A typical dynamic wind tunnel run includes two stages: the tare run and wind-on run. In the tare run the model is oscillated but the wind tunnel is not running. In this run mechanical damping is obtained. The total damping is obtained in the wind-on run in which the model is oscillated with the same frequency and amplitude as during the tare run, but the wind tunnel is running. The dynamic stability derivatives are obtained by subtracting tare run data from wind-on run data.

The equation for the determination of the direct damping derivative in pitch may be written as:

$$M_q + M_{\dot{\alpha}} = \frac{|M_T|}{|\theta|}\frac{\sin\eta}{\omega} - \frac{|M_{To}|}{|\theta_o|}\frac{\sin\eta_o}{\omega_o} \qquad (1)$$