A Method for Designing Multiload Component Dynamometers Incorporating Octagonal Strain Rings

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ABSTRACT—To optimize the design of force dynamometers incorporating octagonal ring elements it is important to be able to predict the dynamometer sensitivities. Previous methods relying on thin ring theory have been inadequate because octagonal rings often have a thickness which cannot be considered thin and, further, the thickness is not uniform. In this paper, empirical equations that describe the deflections, strains and von Mises stresses of individual octagonal rings due to radial, tangential and axial forces are developed using finite-element models. These models are loaded and constrained to simulate the most common uses of octagonal rings in force dynamometers. A nonlinear regression routine is used to develop the above equations from the data given by the finite-element analysis. The performance of these equations is evaluated and presented in tabular form. A procedure is also outlined to describe the use of these equations in the design of six-load-component dynamometers.

List of Symbols

- $A$, $B$, $C$, $D$ = strain-gage locations
- $A'$, $B'$, $C'$, $D'$
- $C_i$ = proportionality constants relating total voltage signals to loads (N/V or Nm/V)
- $d_r$, $d_t$, $d_a$ = radial, tangential and axial deflections respectively of the top surface of ring (m)
- $e_{A}$, $e_{B}$, $e_{C}$, $e_{D}$ = strain at subscripted strain-gage location ($\mu$strain)
- $E$ = Young's modulus (Pa)
- $E_1$, $E_2$, $E_5$, $E_6$ = constants used in developing the equations of deflection of axially loaded octagonal rings
- $f_{a,009}$ = function in axial deflection equation for $r = 0.009$ m
- $f_{d}$, $f_{s}$ = functions in deflection and strain equations respectively
- $f_{VMS} = $ functions describing maximum von Mises stress due to individual loads $F_r$, $F_t$ and $F_a$ respectively
- $F_r$, $F_t$, $F_a$ = radial, tangential and axial forces respectively acting on top of ring (N)
- $F_{d}$, $F_{s}$, $F_{a}$ = forces on a dynamometer (N)
- $M_r$, $M_t$, $M_a$ = moments on a dynamometer (Nm)
- $P_1$, $P_2$, $P_3$ = constants used in developing the equations for tangential strain-gage location

$r$, $t$, $b$ = radius, thickness and base width respectively for octagonal ring (m)
$t^*$, $b^*$ = factors used in the axial deflection and von Mises stress equations
$V_{in}$ = input excitation to Wheatstone bridges (V)
$V_r$, $V_t$ = voltage outputs from Wheatstone bridges corresponding to $F_r$ and $F_t$ respectively (V)
$V_{rt}$, $V_{tt}$ = voltage from bridge on octagonal ring $i$ corresponding to $F_r$ and $F_t$ respectively (V)
$VMS = $ maximum von Mises stress (Pa)
$x$, $y$, $z$ = denoted coordinate system for dynamometer
$t_1$, $t_2$ = width and length respectively of dynamometer (m)
$\theta = $ angular location of point of zero strain due to radial loading measured from the horizontal line passing through the center of an octagonal ring (degrees)

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Introduction

Although a variety of elastic element shapes has been used in multiload-component strain-gage dynamometers (Ewald, 1979; Dubois, 1981; Tani et al., 1983; Wunderly and Hull, 1987), one element widely used is the strain ring (Ito et al., 1980; Hull and Davis, 1981; Shaw, 1984). Figure 1 helps to show the characteristics of a strain ring that make it useful in dynamometry. If the ring is both circular and thin, then a radial force causes zero strain at points C, C', D and D' while the strain at points A, A', B and B' is linearly proportional to . Similarly, assuming that a moment prevents the point of load application from rotating, a tangential force causes zero strain at points A, A', B and B' while the strain at points C, C', D and D' is linearly proportional to . Thus, if strain gages are mounted at the above locations and interconnected into two full Wheatstone-bridge circuits, then a two-load-component dynamometer is realized where each bridge output is responsive to only one load. Six load components can be measured by combining several rings into one dynamometer. Figure 2 depicts a ring configuration of a dynamometer concept offered by Shaw and used by Hull and Davis to measure the six foot/pedal loads in bicycling.

Note that for most applications, octagonal rings are used rather than circular rings. Octagonal rings are preferred because, when compared with circular rings, they require less deflection for an equivalent measured strain. High stiffness is advantageous for maximum frequency response. An additional advantage of octagonal