For large step inputs the acceleration capabilities for the system with and without the damper are compared as:

(a) For the damper in the system

$$a_d = \frac{T_s}{\alpha\beta J_m} \qquad [15]$$

$$\tau_d = \frac{\alpha}{\omega_m} \qquad [16]$$

(b) For the damper disconnected

$$a_w = \frac{T_s}{J_m} \qquad [17]$$

$$\tau_w = \frac{1}{\beta\omega_m} \qquad [18]$$

Hence for the damper disconnected the acceleration is greater by the factor $\alpha\beta$ which, for the system considered, is about 25.

For the system described in this paper the constants have the following values:

$K_1 = 27$
$K_2 = 0.4$ volt deg^{-1}
$K_3 = 375$
$K_4 = 57.3$ deg rad^{-1}
$n = 108$
$K_T = 0.016$ in-oz volt^{-1}
$J_m = 0.72 \times 10^{-4}$ in-oz sec^2 rad^{-1}
$J_s = 1.41 \times 10^{-4}$ in-oz sec^2 rad^{-1}
$J_d = 1.69 \times 10^{-3}$ in-oz sec^2 rad^{-1}
$f_m = 1.23 \times 10^{-3}$ in-oz sec rad^{-1}
$f_d = 0.156$ in-oz sec rad^{-1}
$T_s = 2.4$ in-oz
$\Omega_s = 600$ rad sec^{-1}

Using these values, the transfer function of Equation [10] is found to be

$$\frac{\theta_m}{V} = \frac{75(S + 92.3)}{S(S + 0.65)(S + 825)} \qquad [19]$$

$$\frac{K_1K_2K_3K_4}{n} = 2.15 \times 10^3 \text{ volt rad}^{-1} \qquad [20]$$

$\tau_d = 1.5$ sec
$\tau_w = 0.0585$ sec
$K_t = 7000$ in-oz deg^{-1}

Discussion

G. A. Biernson.[10] Damper compensation is ideally suited for many instrument-servo applications because of the high stiffness and wide bandwidth that can be achieved with rather simple electronics. The dual-mode technique described in this paper provides an excellent solution to the poor synchronizing response which is the main limitation of damper compensation in such applications.

It should be pointed out, however, that when there is significant load inertia, damper compensation is generally inferior to tachometer compensation, because of the following:

(a) The sustained acceleration capability of the motor is much less when coupled to a damper, because the motor must accelerate the damper slug.

(b) For good stability the allowable reflected load inertia with respect to the motor must be quite small in comparison to the damper-slug inertia.

Consequently, the acceleration capability of the output is quite restricted with damper compensation if there is much load inertia.

The acceleration capability of a damper-stabilized motor is equal to the motor torque divided by the total inertia coupled to the motor shaft which includes the inertia of the floating slug and the direct-coupled inertia. When full motor voltage is first applied the damper-stabilized motor can achieve instantaneously a much faster acceleration because it need only accelerate the direct-coupled inertia. However, if it is to sustain an acceleration for a reasonable period of time, it also must accelerate the damper slug, which is usually at least six times as large as the direct-coupled inertia.

The direct-coupled inertia includes the motor-shaft inertia, the reflected load and gear inertia, and the damper-shell inertia. The damper-shell inertia, unfortunately, is from 5 to 10 per cent of the slug inertia and hence may account for as high as 60 per cent of the total direct-coupled inertia. Consequently the allowable value of the reflected load inertia is quite small in comparison to the total inertia coupled to the motor shaft.

The dynamic error of a damper servo in response to a low-frequency input is determined primarily by the acceleration-error coefficient. The value of this coefficient for the servo described in this paper unfortunately has not been mentioned.

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Rufus Oldenburger.[11] The use of clutches as described here to modify the transfer function to improve performance is particularly effective for small servos, especially of the military variety where clutch wear may not be too big a problem. From our studies we have concluded that when it comes to large physical devices, such as governed engines, inertia-damping stabilization is out of the picture because of bulk, cost, and other factors. Further, our experience is that, when the clutch is slipping, the force that exists depends on a number of unknowns and cannot normally be taken into account in accurate analytical studies. If the clutching and declutching are done quickly enough this may not cause trouble.

[11] Director of Research, Woodward Governor Company, Rockford, Ill. Mem. ASME.

Authors' Closure

We appreciate the time Mr. Biernson spent in preparing his comments although they are not considered to be appropriate. The purpose of the paper was to describe a technique for improving the response of a particular system and not to discuss the relative merits of various compensation schemes.

Also we do not consider it particularly unfortunate that the acceleration-error coefficient was not mentioned.