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SEMIACTIVE FLUTTER CONTROL OF WING/STORE SYSTEM WITH ELECTRO-MAGNETIC FRICTION DAMPER

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1. INTRODUCTION

It has been shown [1] that for some wing/store configurations application of an impact damper can have significant effects on raising the flutter speed. In reference [2], it is demonstrated that semiactive flutter control is feasible by adding gain dispatch control to the gap of the impact damper. In the present work an alternative to the damper, namely an electro-magnetic friction damper, is investigated. It is installed at the junction of the wing/store system, and automatic control of the friction force is introduced to suppress wing/store flutter. Numerical simulation results of the flutter control process are verified by wind tunnel tests.

2. WING/STORE SYSTEM WITH ELECTRO-MAGNETIC FRICTION DAMPER

The schematic diagram of an electro-magnetic friction damper is shown in Figure 1. When the electrical circuit is established, the armature is pressed to the yoke by the electro-magnetic attraction force, proportional to which a friction force is introduced between the friction disc and the yoke. The attraction force is proportional to the square of the magnetic induction intensity which itself is proportional to the current intensity fed to the coil of the damper. If the damper is used to attenuate the rotational motion of a single-degree-of-freedom system, then the frictional torque produced by the damper varies in proportion to the intensity squared of the current fed to the damper.

The wing/store wind tunnel model of reference [3] is refitted with an electro-magnetic damper and is used in the present study. An outline drawing of the model is shown in Figure 2. The wing/store model system has three degrees of freedom, namely wing roation h and α about two perpendicular axes OX and OY respectively and the store pitching β. Pertinent parameters of the model are introduced in Table 1.

In Table 1, L_1–L_5 are lengths denoted in Figure 2, μ_h, $\mu_{h\alpha}$, μ_α are the generalized masses of the wing, m_β is the store mass, μ_β is moment of inertia of the store, K_h K_α, K_β are the stiffness coefficients of h, α, β respectively. The basic units used are meter (length), kilogram (mass), and second (time).

Figure 3 is a perspective sketch of the store with friction damper. Simplified frictional torque variation law with square wave time history (see Figure 4) is employed in the mathematical model of the wing/store aeroelastic system. The equation of motion of the system can be written as

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{K}\mathbf{x} + \mathbf{T}(\mathbf{x}) = q\mathbf{A}\mathbf{x} \tag{1}$$

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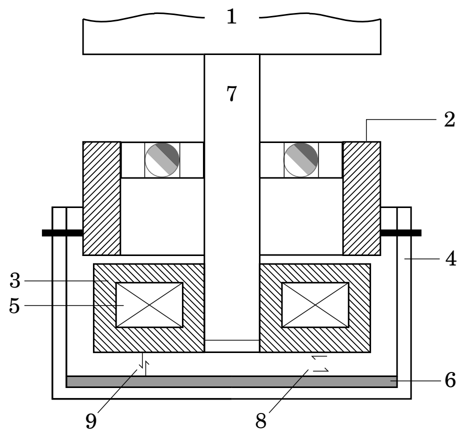

Figure 1. Schematic sketch of electro-magnetic damper. 1 wing; 2 store (rotating about axle); 3 magnetic yoke; 4 armature; 5 coil; 6 friction disc; 7 axle; 8 friction force; 9 attraction force.

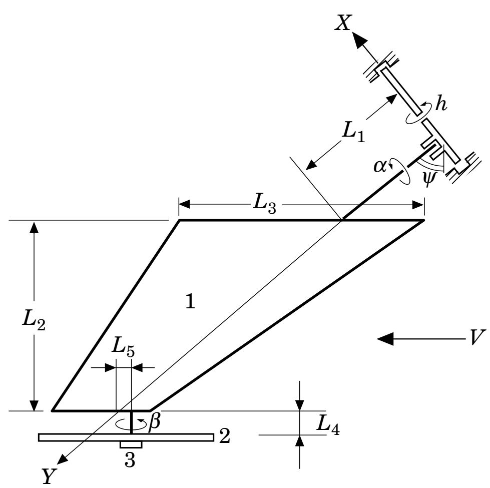

Figure 2. Sketch of wing/store model. 1 wing; 2 store; 3 electro-magnetic friction damper.

TABLE 1

Model parameters

L_1	L_2	L_3	L_4	L_5	ψ (°)	μ_h
0·25	0·4	0·5	0·04	0·025	50	0·2665
$\mu_{h\alpha}$	μ_α	m_β	μ_β	K_h	K_α	K_β
−0·0048	0·0035	0·075	0·0023	326·46	4·29	0·48

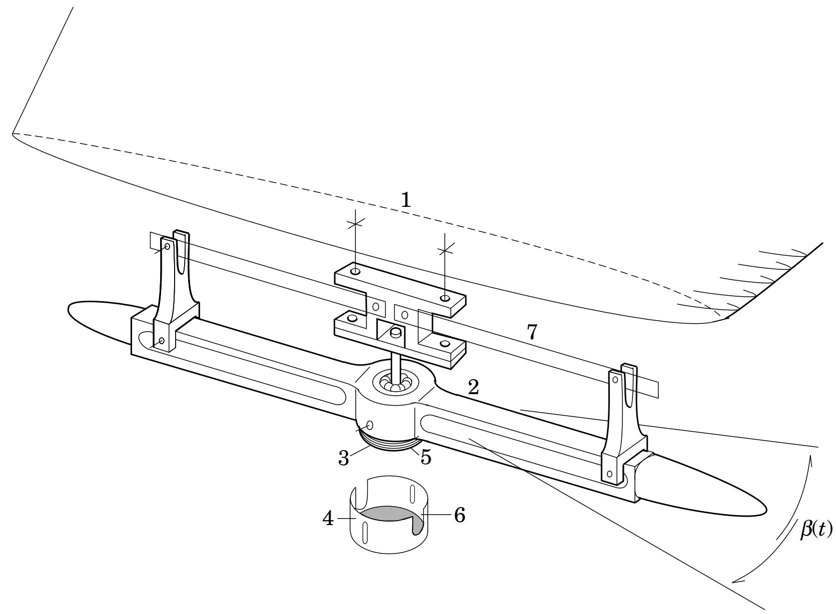

Figure 3. Sketch of external store with electro-magnetic friction damper. 1 wooden model wing; 2 external store; 3 magnetic yoke; 4 armature; 5 coil; 6 friction disc; 7 leaf spring.

where $\mathbf{x} = [h, \alpha, \beta]^{\mathrm{T}}$, $\mathbf{M}$, $\mathbf{K}$ are the mass and stiffness matrices respectively,

$$\mathbf{M} = [m_{ij}],\ i, j = 1\text{–}3, \qquad m_{11} = \mu_h + m_\beta e_2^2 + \mu_\beta \sin^2 \psi,$$

$$m_{12} = m_{21} = \mu_{h\alpha} + m_\beta e_1 e_2 - \mu_\beta \sin \psi \cos \psi, \qquad m_{22} = \mu_\alpha + m_\beta e_1^2 + \mu_\beta \cos^2 \psi,$$

$$m_{31} = m_{13} = -\mu_\beta \sin \psi, \qquad m_{32} = m_{23} = \mu_\beta \cos \psi, \qquad m_{33} = \mu_\beta,$$

$$e_1 = (L_5 + L_4 \operatorname{tg} \psi)\cos \psi, \qquad e_2 = L_1 + (L_2 + L_4) \sec \psi - (L_5 + L_4 \operatorname{tg} \psi)\sin \psi,$$

$$\mathbf{K} = \operatorname{diag}\,[K_h, K_\alpha, K_\beta].$$

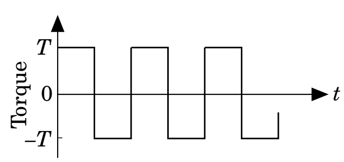

Figure 4. Wave form of the frictional torque.

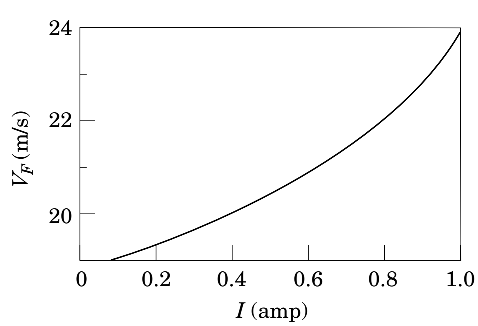

Figure 5. Variation of flutter speed with current intensity.

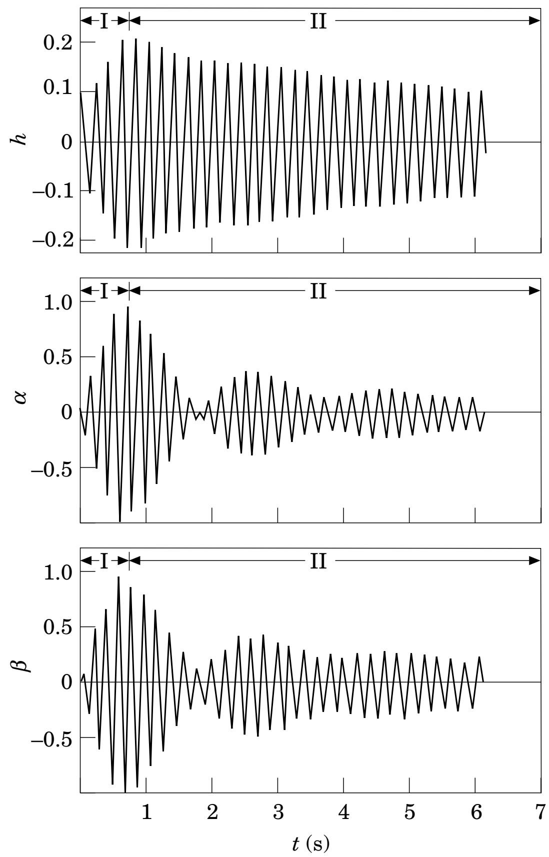

Figure 6. Numerical simulation of closed circuit control time history. $V = 20$ m/s, (I) $I = 0$, (II) $I = 0{\cdot}4$.

A is the fully unsteady aerodynamic coefficient matrix deduced by the Roger fitting method, q is the dynamic pressure of the air flow, $\mathbf{T}(\mathbf{x}) = [0, 0, T(\beta)]^{\mathrm{T}}$, and $T(\beta)$ is the frictional torque obeying the following simplified law:

$$\begin{cases} T(\beta) = T & \text{for } \beta > 0 \\ T(\beta) = -T & \text{for } \beta < 0 \end{cases} \tag{2}$$

$T = cI^2$, where I is the electric current intensity in amperes, and c is a proportional constant determined by relevent physical parameters of the damper.

By numerical simulation, in general, a flutter speed V_F can be found for a definite value of I, thus a curve of V_F versus I is obtained as shown in Figure 5.

3. AUTOMATIC CONTROL OF DAMPER FRICTION

Damper friction is a structural parameter of the whole system, its variation being a kind of variation of the physical property of the system. Hence gain dispatch control can be used to realize semiactive control of the system. The control law introduced to the system equations (1), (2) is

$$\begin{aligned} &I = 0 && \text{when} && t = 0 \\ &I = (I_i + \Delta I) && \text{when} && \beta > \beta_0 \\ &I = I_i && \text{when} && \beta < \beta_0 \end{aligned}$$

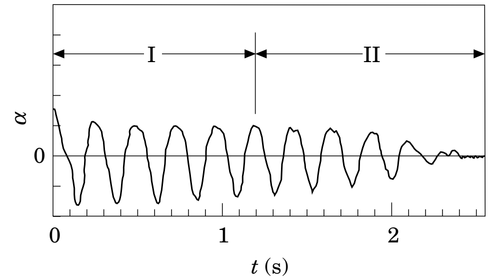

Figure 7. Test record of semiactive control process at $V = 24$ m/s, $I_1 = 0$, $I_2 = 0{\cdot}12$.

where β_0 is the threshold value of the store pitching amplitude, I_i is preceding current intensity fed to the damper, ΔI is the step increment value of the current.

Numerical simulation results of responses of the system with the friction control circuit are shown in Figure 6. It can be seen that in stage I, when the control circuit is open, divergent flutter occurs and the motion turns to damping oscillation (state II) as soon as the control circuit is closed.

4. WIND TUNNEL TESTS

A gain dispatch control system was constructed and connected to the current feeding circuit of the damper. The wind tunnel used was of a closed circuit type, with a circular test section of 1 m diameter and maximum air speed of 60 m/s.

The model undergoes sustained oscillation at $V = 24$ m/s, when current was not being fed to the damper. The sustained oscillation is identified to be limit cycle flutter due to structural non-linearities existing in the system. When a steady current of $I = 0{\cdot}12$ A is fed to the damper, the air speed can be raised up to $V = 25$ m/s when flutter occurs. The effects of semiactive control can be seen from Figures 7 and 8 in which the time histories of transition from flutter to damping oscillation are shown. In these figures I_1 is the steady current fed to the damper in stage I. After the control circuit is closed (denoted by stage II) the current was increased step by step to I_2 when flutter was suppressed. Figure 7 and Figure 8 correspond to $V = 24$ m/s and 25·5 m/s respectively. The augmented flutter speed obtained in the wind tunnel tests is higher than that of the numerical analysis. This is partly due to the fact that the mathematical model of the friction used in the analysis is oversimplified.

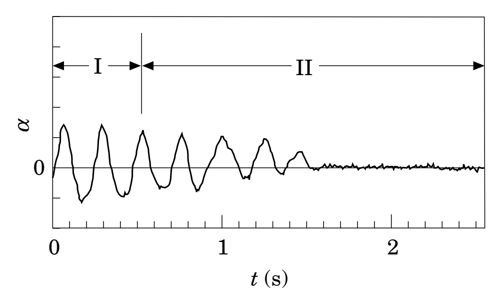

Figure 8. Test record of semiactive control process at $V = 25{\cdot}5$ m/s, $I_1 = 0{\cdot}12$, $I_2 = 0{\cdot}24$.

5. CONCLUDING REMARKS

A simple automatic control device has been adopted to adjust the friction force of an electro-magnetic damper, which is installed at the junction between the external store and the wing model. The damping effects of the friction force is utilized to suppress the wing/store flutter. Feasibility of this semiactive flutter suppression scheme by using controlled electro-magnetic damper is demonstrated by numerical analysis and is verified by wind tunnel tests.

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