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Hybrid Tension-Compression Pneumatic Actuators for Active Leveling, Tuning & Damping of Vehicle Suspensions & Engine Mounts

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0. ABSTRACT

This paper features the innovative use of pneumatic tension actuators in combination with conventional compression air-springs so as to separate and independently control both the load-leveling function and the effective stiffness or spring-rate characteristic. Because the air-supply to the actuators is actively manipulated and controllable to frequencies above the dominant vibration modes of the structure, both active damping and adaptive tuning are readily provided. Simple dynamic simulations verify that such hybrid configurations will prove beneficial for vehicle suspensions and machine mountings.

1. INTRODUCTION

Compression air-springs were introduced in the 1930s as a vibration-isolating and load-leveling suspension for automobiles, trucks and buses. With advances in tire fabrication technology, hundreds of millions of these devices have been used to date. More recently, various modifications have been employed to improve ride comfort and road handling, including both semi-active and fully-active implementations. Beside controlling natural frequencies and damping, these systems must minimize dynamic fluctuations in wheel loadings to maintain adequate steering, traction and braking.

Unfortunately, rapidly varying air-pressure in conventional air-springs simultaneously changes both wheel loads and suspension stiffness, and is further handicapped by the large air volumes involved. These undesirable features are avoided with the combined use of both compression and tension actuators proposed here.

2. STATIC ACTUATOR CHARACTERISTICS

For well over a century, pneumatic actuators have been in wide use, but the pneumoelastic or flexural form is of more recent origin. Yet it is also interesting that both compression and tension actuators can be considered as distinct configurations of a single geometry as in Figure 1, derived from the extended bicone model of Paynter [1]. Compression actuators, or "pushers," are generally oblate in form, elongating with increased pressure under constant load, as indicated in Figure 1 region A. In contrast, tension actuators, or "tuggers," are prolate in form, contracting with increased pressure under constant load, as in Figure 1

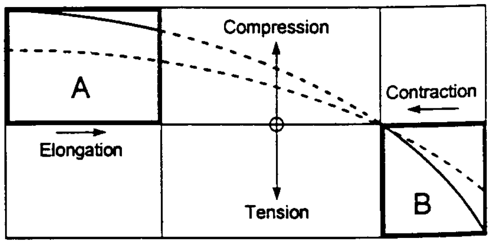

Figure 1. Pneumoelastic Actuators (A: Oblate Compression; B: Prolate Tension; Solid Curve: Full Pressure; Dashed Curve: Reduced Pressure)

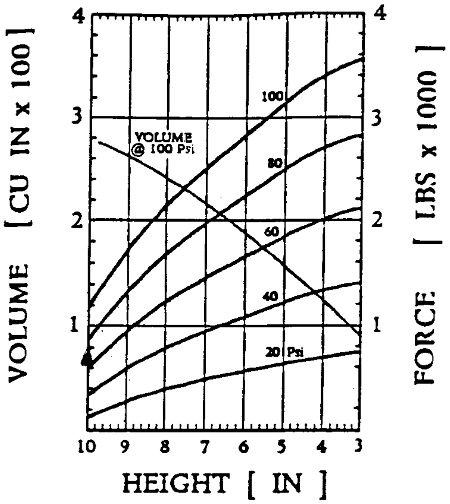

Figure 2a. Firestone (26) Airmount™ Characteristic (compression actuator)

region B. Actual static characteristics of commercial actuators are shown in Figure 2 with the Firestone [2] Airmount™ in Figure 2a and the Dynaflex™ in Figure 2b, as given by Paynter [1]. Further discussion of tension actuators is provided in [3].

3. HYBRID SUSPENSION STATICS

Alternative hybrid configurations are possible wherein the pusher(s) and tugger(s) operate antagonistically. For example, Figure 3 shows the particular case of two tuggers on each side of a single pusher, so providing independent control of effective stiffness and position.

Using the previously noted simplified bicone models, Figure 4 portrays the resultant combined static characteristics arranged to maintain desired fixed deflection under a doubling of applied load. This would not be possible with the pusher alone and requires the pusher pressure to increase appropriately while the opposed tugger pressures simultaneously decrease the proper amount. These pressure changes can be readily obtained through the appropriate control.

4. CONTROLLED DYNAMIC RESPONSE

Figures 5a,b,c depict the simulated transient response of the fully-active hybrid suspension system resulting from a sudden doubling of the applied load. A rudimentary control model is used in which load-sensing is assumed and the tuggers and pusher all participate in the control. However, only tugger pressure responds to velocity to provide effective damping; this takes full advantage of the substantially smaller air demands of tuggers to yield faster response.

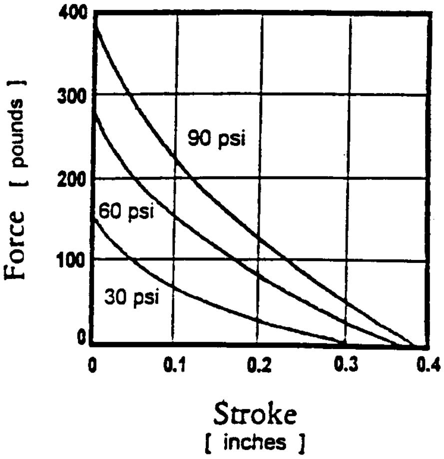

Figure 2b. Dynacycle Dynaflex™ (D125) Characteristic (tension actuator)

Other simulation studies demonstrate near optimal behavior can be achieved, as well as indicate the effects of adaptive tuning by varying stiffness under constant load and deflection. Because the air supply to the actuators is actively manipulated and controllable to frequencies above the dominant vibration modes of the structure, both active damping and adaptive tuning are readily provided.

5. CONCLUSIONS

Simplified models have demonstrated the utility of the hybrid units for active suspensions. In response to an external command, the impedance characteristics can be tuned. In this configuration, the actuators are highly effective for suppression of vibrations, even in the face of significant disturbance. Applications are promising for vehicle suspension and for engine and machine mountings.

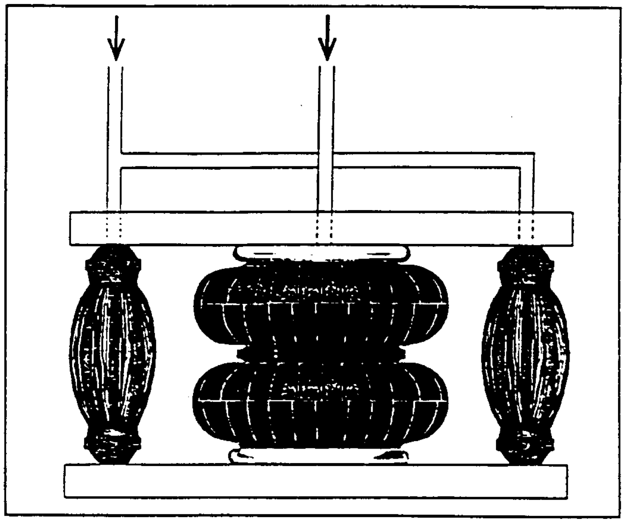

Figure 3. Hybrid Tension-Compression Pneumatic Actuator consisting of Single Pusher and Two Tuggers

6. REFERENCES

[1] Paynter, H.M., "Thermodynamic Treatment of Tug-&-Twist Technology: Part 1. Thermodynamic Tugger Design," Proceedings of the Japan-USA Symposium on Flexible Automation, *ed.* K. Stelson and F. Oba, Boston, MA, July 7-10, 1996, pp.111-117.

[2] Firestone, Engineering Manual & Design Guide, Airstroke Actuators and Airmount Isolators, Noblesville, IN, 1986.

[3] Chou, C.P. and Hannaford, B., "Measurement and Modeling of McKibbin Artificial Muscles," IEEE Transactions on Robotics and Automation, Vol. 12, No. 1, Feb. 1996, pp. 90-102.

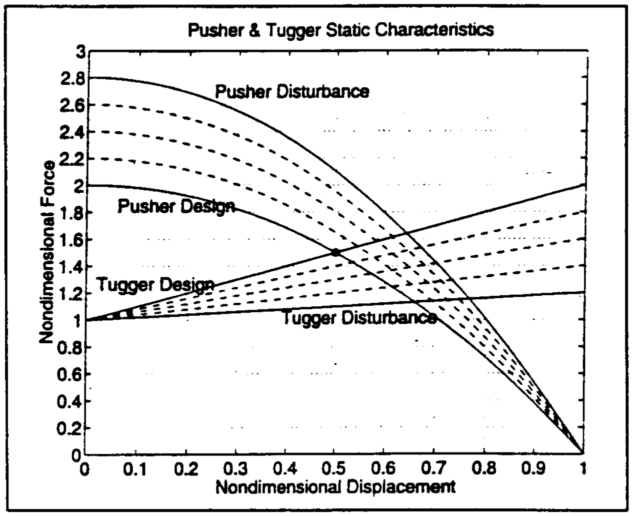

Figure 4. Static Characteristic of Pusher and Tugger

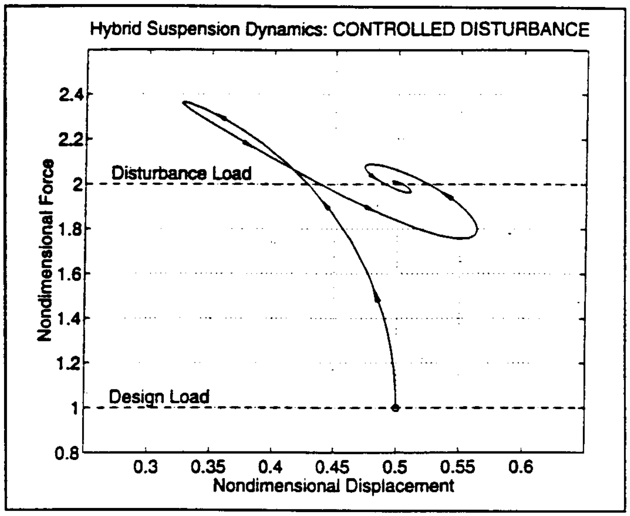

Figure 5a. Nondimensional Force-Displacement Characteristic for Controlled Disturbance

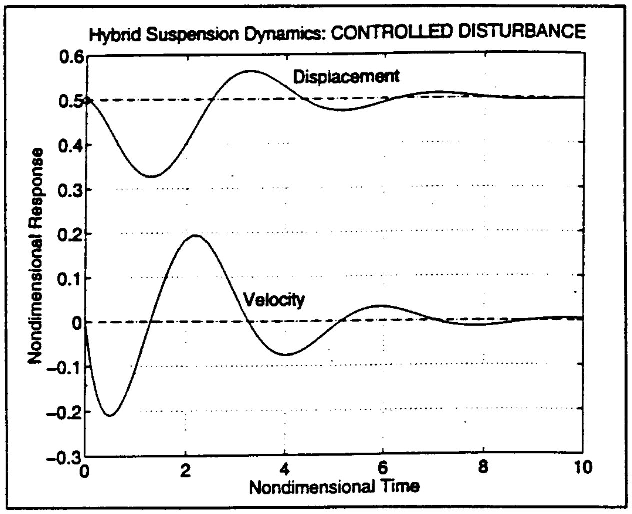

Figure 5b. Nondimensional Displacement and Rate History for Controlled Disturbance

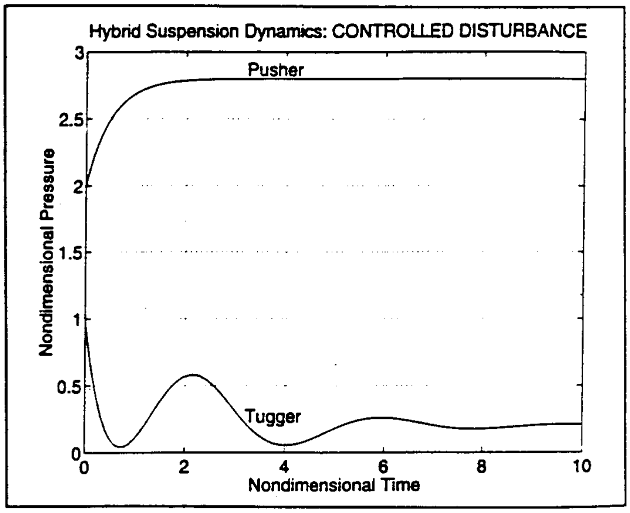

Figure 5c. Nondimensional Pressure History for Controlled Disturbance