STIFF AND SOFT STEWART PLATFORMS FOR ACTIVE DAMPING AND ACTIVE ISOLATION OF VIBRATIONS

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Abstract:
As future astronomic missions will require more and more stringent resolution requirements, the high demand for an environment clean of vibrations and disturbance appears. This also leads to the need for high precision steering devices for fine pointing of sensitive optics with the highest possible accuracy. Several methods exist to reduce vibration levels: the first consists in isolating the sensitive system from the perturbation and the second in damping the structure vibration modes. Therefore, two Stewart platforms have been designed, manufactured and tested. The first is a soft hexapod that provides 6 degree-of-freedom (DOF) active isolation and the second is a stiff hexapod that provides active damping to whatever flexible payload attached/mounted to it. In addition, both hexapods have steering capabilities.

Introduction

The two Stewart platforms presented in this paper are based on the cubic configuration, more details about cubic configuration are shown in [1]. The legs of the soft hexapod consist in soft electro-dynamic actuators. This hexapod consists mainly of two plates connected to each other by six legs. Each leg of the soft Stewart platform contains a voice coil electro-dynamic linear actuator, a force sensor and two flexible joints. This Stewart platform is aimed to be used in active vibration isolation. Only active control can achieve simultaneously high isolation performances (ñ40 *dB/decade* attenuation rate at high frequency) and the stabilisation of the suspension modes. The system is based on a spring mass device with minimum passive damping, provided with pure force generators, collocated vibration sensors and a decentralised control law. A positioning/pointing control layer can also be added to the system.

The second Stewart platform uses high-stiffness piezoelectric actuators in each leg. The legs of this Stewart platform consist of a piezoelectric amplified actuator, a force sensor and two flexible tips. Using universal or spherical joints here is avoided to achieve high resolution without backlash or friction. This hexapod is made to act as a vibration damping interface from one side and a precision pointing device from the other side. Using a mechanical truss structure as a payload, the platform showed high authority in active damping of the vibrations. Another application for this hard actuator hexapod is the high-precision pointing device for space applications. The kinematics of the hexapod helps to amplify the motion of the mobile platform (more details about kinematics are discussed in [2]). Although the stroke of the actuator does not exceed 55 μm the translation and rotation strokes of the upper platform are 90,103 and 95 μm in the *x, y* and *z* directions respectively and 1300, 1150 and 700 μrad around the *x, y* and *z* directions respectively.

Soft Stewart platform

The design of this soft Stewart platform is based on the cubic configuration where the two main plates here are two aluminium triangles connected to each other by means of six active struts. Each strut consists mainly of a voice coil actuator, a force sensor and two flexible joints as shown in Fig.1.

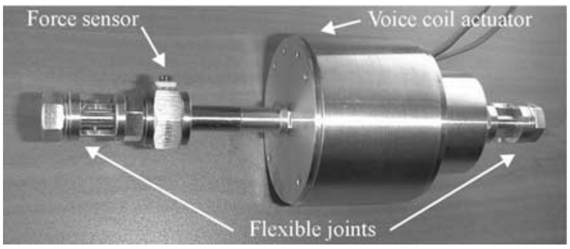

Fig. 1: *The active assembly leg of the of soft Stewart platform*

Fig.2 shows the hexapod; where Fig.2(a) is a side view showing the inclination angles of the legs according to the cubic configuration and Fig.2(b) is a general view showing the triangular plates and their connection to the legs. In the design of this soft system, one should take into account many parameters particularly the design and manufacturing of the current carrying coils, the membranes and the flexible joints.

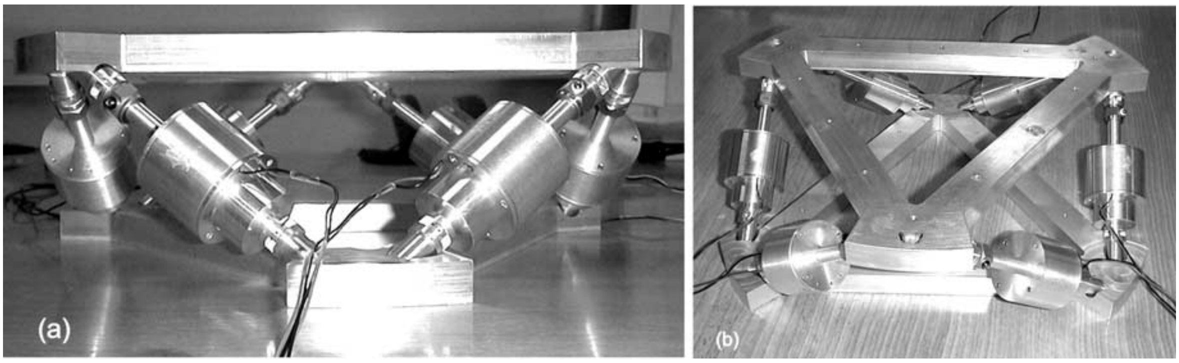

Fig. 2: *Soft Stewart platform. (a): side view, (b): General view of the hexapod*

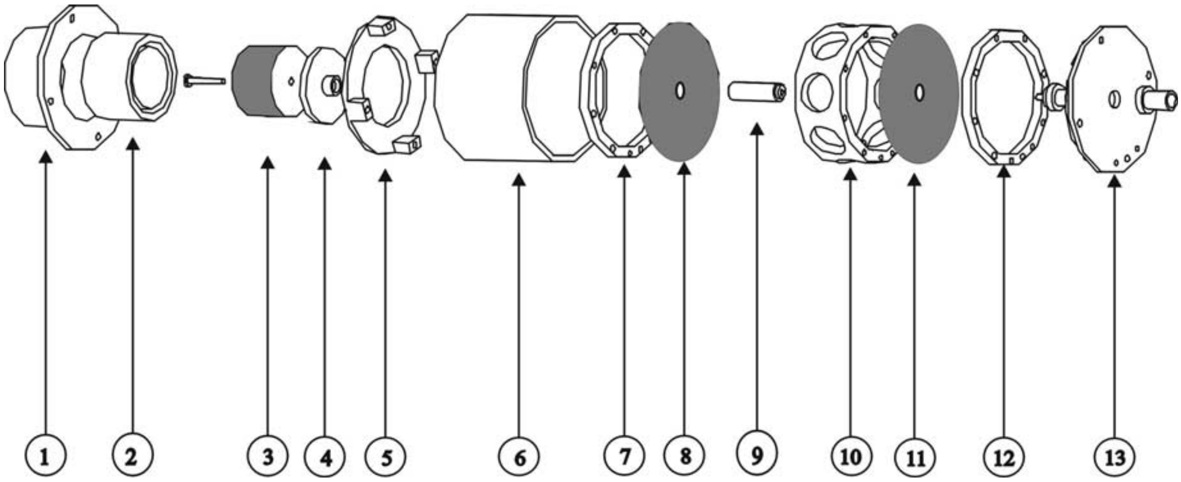

Fig 3: *Exploded view of the actuator. (1): Magnet holder, (2): Magnet, (3): coil, (4): Coil backplate, (5): Magnet-membrane spacer, (6): Envelope, (7): Spacer-1, (8): Membrane-1, (9): Central rod, (10): Membrane spacer, (11): Membrane-2, (12): Spacer-2, (13): Cover*

Active strut design

The voice coil actuator integrated in the leg consists of a permanent magnet and a current carrying coil. The permanent magnet is a radial polarity toroid magnet with a ferromagnetic metal core manufactured by BEI KIMCO. The current carrying coil has been development and manufacturing in house because of its significant contribution in the damping content in the form of back electro motive force (*e.m.f*). This *e.m.f* adds passive damping to the system in the axial direction of the leg which leads to reduce the roll-off rate after the corner frequency [3]. Looking over at the previous designs, we find in [5] that the designs include the effect of this damping in the system in spite of its high influence on the high frequency attenuation. On the contrary, in [8], a carbon fiber composite material has been used to construct the coil holder (bobbin) in order to minimize the *e.m.f* and thus reducing the passive damping. The new contribution in our design is that we could get rid of this problem at all by simply winding the coil and sticking the turns to each other using a special strong adhesive without having any holder from any kind. In order to align the coil and the magnet up together, a set of components and connections are manufactured and installed as shown in the exploded view in Fig.3. To allow the current carrying bobbin to move freely through the air gap of the permanent magnet in the actuator, an alignment system is needed [4][5]. Two *Beryllium Copper* flexible membranes have been designed and manufactured at the ULB to achieve the following characteristics: (*i*) low axial stiffness, (*ii*) high radial stiffness, (*iii*) no friction or backlash, (*i*v) non-magnetic characteristics and, eventually, (v) light weight and small size. To connect each leg to either the upper or the lower plate, flexible joints are designed, tested and manufactured at the ULB, (deep discussion about flexible joints is shown in [6]). These joints behave like spherical joints, but with the following characteristics: (*i*) high axial and shear stiffness, (*ii*) low bending and torsion stiffness and (*iii*) minimum friction and backlash.

Stiff Stewart platform

In this part, a stiff active damping interface is proposed. It can be used either as a support for payloads or to connect arbitrary substructures. It has the ability to introduce damping in the mechanical system attached to it while remaining stiff. The active interface consists of a six-degree of freedom Stewart platform, a standard hexapod with a cubic architecture. Each leg of the active interface is made of a linear piezo electric actuator, a collocated force sensor and flexible tips for the connection with the two end plates. The control architecture is based on six local/decentralized Integral Force Feedback controllers. By providing the legs with strain or elongation sensors, this active interface can also be used as an interface with infinite stiffness at low frequency (i.e. for machine tools), a 6 d.o.f. Positioning and steering device for space applications as well as a micro vibration isolator.

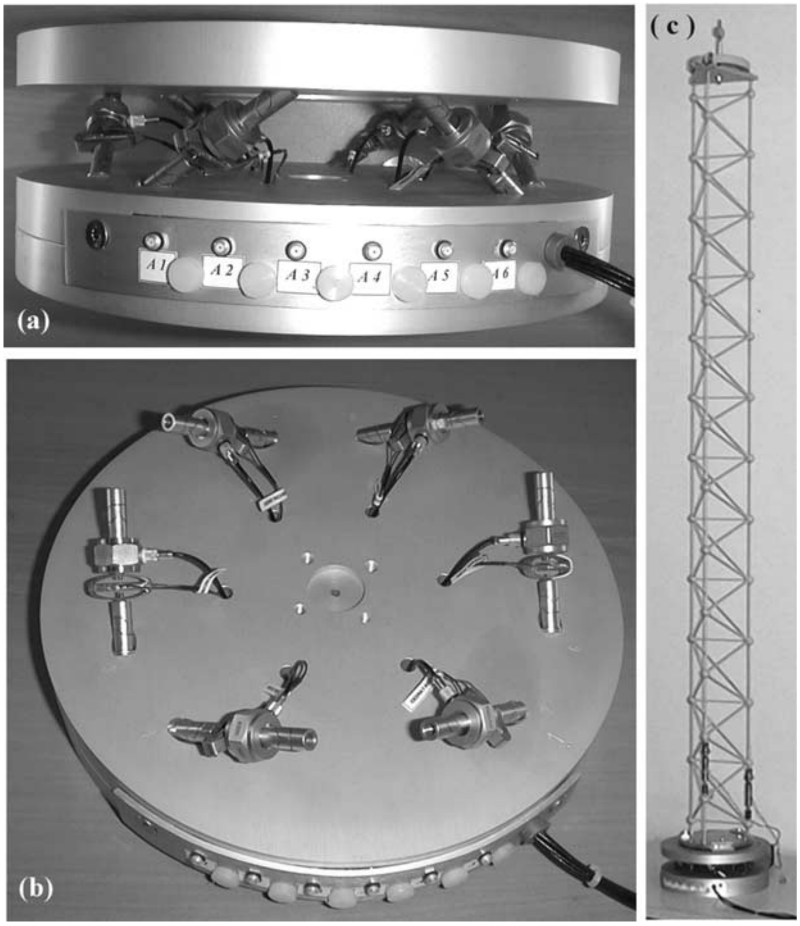

Fig.4: *The Stiff Stewart platform (a): complete hexapod (b): the hexapod with the upper plate removed, (c): test set-up*

The hexapod assembly

Fig.4 (a) shows a picture of the complete Stewart platform and Fig.4 (b) shows the same but with removing the upper plate. The two plates are circular aluminum plates connected to each other by six active legs; the legs are mounted in such a way to achieve the geometry of cubic configuration. Each active leg consists of a force sensor (B&K 8200) and an amplified piezoelectric actuator (Cedrat Recherche APA50s) as shown in Fig.5. To avoid the problems of friction and backlash in the joints, flexible tips were used instead of spherical joints. These flexible tips have zero friction, zero backlash, high axial stiffness and relatively low bending stiffness. The existence of this bending stiffness makes a limitation for the control authority because it shifts the transmission zeros to a higher frequency, which will decrease the damping effect expected from each closed-loop pole.

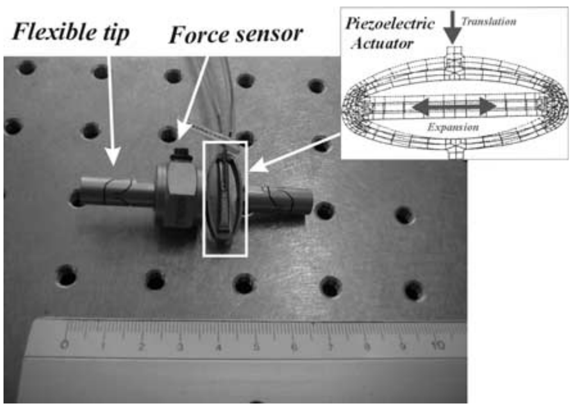

Fig.5: *The active leg assembly of the stiff Stewart platform*

Active damping results

In order to evaluate the damping performances of the interface, the hexapod is connected to a flexible payload, a 150 cm long steel truss structure (see Fig.4 (c)). Decentralized Integral Force Feedback control scheme was applied to the experimental system. The six independent controllers have been implemented on a DSP board. The six loops have been closed separately and, although the control loops were independent, the feedback gains used in all the loops are identical. Fig.7 presents some experimental results. The time response shows the signal from one of the force sensors located in the legs; the truss is subjected to an impulse at middle height, without then with control. The frequency responses (with and without control) are obtained between a perturbation signal applied to the piezo actuator of one the leg and its collocated force sensor. One can see that fairly high damping ratios can be achieved for the low frequency modes (4-5Hz) but also significant damping in the high frequency modes (40-90Hz). Unfortunately, the results on the torsion mode have been disappointing, probably due to the flexion stiffness in the flexible tips.

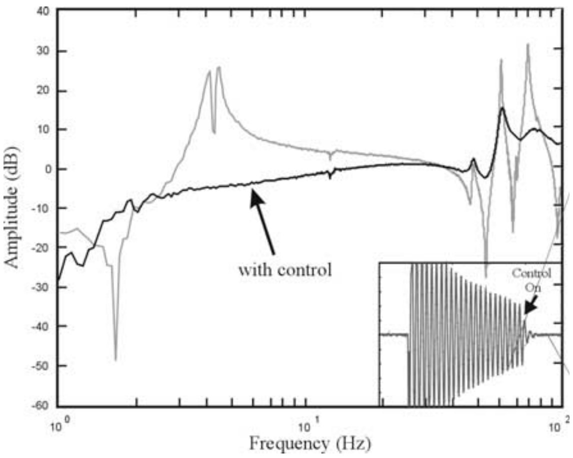

Fig.6: *Experimental time response and FRF of the truss mounted on the active interface.*

Conclusion

This paper described two new generations of soft and stiff mount Stewart platforms. In a brief discussion we tried to show the design, assembly and configuration of the two hexapods. The control technique applied to the stiff hexapod proved to give good active damping authority on the low frequency modes as well as the high frequency ones. Regarding the soft hexapod, our discussion was concentrated on the design and technological aspects. The design and manufacturing of the flexible joints proved to have high influence on both; the active suppression of vibrations induced by the low frequency suspension modes and the active isolation of vibrations caused by high frequency excitations. On the other hand, a good design of the actuator and the flexible membranes can contribute significantly in increasing the isolation of vibrations provided to the system.

Acknowledgment

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Reference

[1] Z.J. Geng and L.S. Haynes, Six degree-of-freedom active vibration control using the Stewart platforms, *IEEE Transactions on Control Systems Technology*, 2(1), 45-53, March 1994.

[2] A. Abu Hanieh, A. Preumont & N. Loix, piezoelectric Stewart platform for General purpose Active damping and precision control, *9th European Space Mechanism and Tribology Symposium,* September, 2001. Liege , Belgium.

[3] A. Preumont, *Vibration control of active structures*, 1st. ed., Kluwer Academic Publishers, 1997

[4] J.E.McInroy, J.F.O'Brien and G.W.Neat, Precise, fault-tolerant pointing using a Stewart platform, *IEEE/ASME Transactions on Mechatronics*, Vol.4, No 1, pp.91-95, March 1999.

[5] J. Spanos, Z. Rahman & G. Blackwood, A soft 6-axis Active vibration isolator, *Proceedings of the American Control Conference*, 412-416, June, 1995.

[6] D. Thayer, J. Vagner, A. von Flotow, C. Hardham and K. Scribner, Six-axis vibration isolation system using soft actuators and multiple sensors, *AAS*, vol. 064, 497-506, 1998.

[7] A. Preumont, A. Francois, F. Bossens and A. Abu-Hanieh, ìForce feedback versus acceleration feedback implementation in active vibration isolationî, *Journal of sound and vibration*, submitted in August 2001.

[8] J. Fochage, T. Davis, J. Sulivan, T. Hoffman & A. Das, Hybrid active/passive actuator for spacecraft vibration isolation and suppression, *SPIE,* 2865:104-122, March 1996.