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STEWARD PLATFORM. APPLICATION OF SMART FLUID DAMPERS IN THIS FIELD

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Abstract: In the paper, the main types of Stewart platforms are presented and some of their specific applications in the field of vibration insulation, at precision measurement devices, used in the space technology, especially for the communication antennas and solar cell panels [1], [2]. In the specialty literature the component parts (dampers and actuators with magnetorheological fluid) are well studied, but the Stewart platform realized with this components are not enough approached in the researches until now. Using magnetorheological fluid components in the construction of Stewart platforms leads to significant decreasing of costs and also to more simple and precision control.

1. INTRODUCTION

Parallel platform mechanisms with 6 degrees-of-freedom (DOF) are ideal candidates for precision positioning applications. Compared to serial kinematic mechanisms, their 6 kinematic chains give them greater load carrying capacity, higher stiffness, the ability to remain stable in the unpowered configuration, and redundancy in motion. Many of the precision positioning applications are located in environments where certain degrees of disturbances exist. These disturbances in the form of vibrations degrade the performance of the sensitive instruments needed for precision positioning. Therefore, it is important to create a vibration-free environment to enable precision positioning. From a design perspective, it would be logical to have a parallel platform mechanism which is inherently an ideal mechanism for precise positioning to provide vibration isolation at the same time.

The robustness and the simple mechanical design of magnetorheological (MR) dampers make them a natural candidate for a semi-active control device. They require minimal power while delivering high forces suitable for full scale applications. They are fail-safe since they behave as passive devices in case of a power loss [3]. MR fluids are suspensions of small iron particles in a base fluid. They are able to reversibly change from free-flowing, linear viscous liquids to semi-solids, having controllable yield strength under a magnetic field. When the fluid is exposed to a magnetic field, the particles form linear chains parallel to the applied field. These chains impede the flow and solidify the fluid in a matter of milliseconds. This phenomenon develops a yield stress which increases as the magnitude of the applied magnetic field increases [4].

In literature, the most known model to characterize the behavior of MR dampers is the Bingham plastic model. This model is an extension of the Newtonian flow and it is obtained by also taking into account the yield stress of the fluid. It assumes that flow will occur when the dynamic yield stress is reached. The total stress is given by

$$\tau = \tau_y(\dot{\gamma}) + \eta\dot{\gamma}, \tag{1}$$

where τ_y is the yield stress induced by the magnetic field, $\dot{\gamma}$ is the shear rate and η is the viscosity of fluid. In this model, the relationship between the damper force and the shear velocity may also be given as

$$F = \begin{Bmatrix} F_y\, sgn(\dot{x}) + C_0\dot{x}, \dot{x} \neq 0 \\ -F_y \prec F \prec F_y, \dot{x} = 0 \end{Bmatrix}, \tag{2}$$

where C_0 is the post-yield damping coefficient and F_y is the yield force. In the post-yield part, the slope of the force-velocity curve is equal to the damping coefficient which is essentially the viscosity of the fluid, η. Both C_0 and F_y are functions of the control current input, *i,* and can be modeled as second order polynomial functions:

$$F_y(i) = F_{yc}i^2 + F_{yb}i + F_{ya}, \tag{3}$$

$$C_0(i) = C_c i^2 + C_b i + C_a. \tag{4}$$

The model coefficients may be found by minimizing the mean square error between the experimental and the model-predicted damper force. The values used in this work were experimentally calculated by Ni et al. and are as follows, [5]:

$$F_y(i) = -39.8i^2 + 95.1i + 21.0, \tag{3}$$

$$C_0(i) = 25.6i^2 + 376i + 220. \tag{4}$$

Other MR damper fluid models in the literature include the Herschel-Bulkley model, which takes into account the post-yield shear thinning and thickening behavior and the Bouc-Wen model, where the parameters of the model can be adjusted to control the linearity in the unloading and the smoothness of the transition from the pre-yield to the post-yield region [6], [7].

2. STEWART PLATFORM

While passive vibration control and active vibration control have been extensively used in parallel platforms, a 6 DOF parallel platform which uses semi-active vibration control has not received as much attention. Advantages of semi-active control include reduced cost (by using a simpler actuator intended for only positioning), reduced power requirements, and improved stability. Each leg of the platform is modeled as a 2 DOF system with an MR damper for adjustable damping, in parallel with a stiffness element and in series with an actuator used for positioning. The vibration isolation performance of the parallel platform mechanism and its positioning capability are quantified through simulations. Simulation results show that MR dampers are effective in 6 DOF vibration isolation applications when they are incorporated into parallel platform mechanisms.

Disturbances in the form of vibrations can degrade the performance of sensitive equipment. As technology advances, more and more precision is expected from instruments used in a broad range of applications (such as machining, precision pointing, and space applications). Completely removing the source of vibration is impossible as external disturbances or vibration generating equipment will always be present. Therefore, the goal should be to isolate the vibrations at the interfaces between the vibration source and the sensitive equipment. This is where parallel kinematic mechanisms emerge as an ideal candidate. Due to their six kinematic chains, they have greater load carrying capacity, higher stiffness, the ability to remain stable in the unpowered configuration, and redundancy in motion (which makes them more tolerant to positioning errors) compared to serial kinematic mechanisms (Anderson *et al*., 2004; Hall *et al.,* 2003). They also have the minimum number of actuators to generate 6 DOF motion. These advantages make them ideal for precision positioning applications. If precision positioning and the ability to isolate vibrations in all 6 DOF are combined in the same mechanism, this would result in significant savings in system complexity and weight (Geng and Haynes, 1994). Geng and Haynes (1994) also point out that compared with a truss mechanism where the forces at the connection modes include components in all 6 DOF; all forces transmitted between the top and bottom plates of a parallel mechanism are purely axial forces of the actuators, assuming that the gravity and the inertial load of the connectors are neglected. If these axial forces can be successfully decoupled, they can be calculated and the vibrations caused by these forces can be eliminated (Geng and Haynes, 1994).

The literature offers a few examples of parallel platforms that aim is to combine precision positioning and vibration isolation in the same mechanism. All of these use either passive or active control, or a combination of both. Active control (piezoceramic, electromagnetic, magnetostrictive, and voice-coil actuators are possible candidates) is used for positioning and also reduces vibration transmissions at low frequencies. Passive control (elastomer, fluid damping and eddy currents are commonly used) attenuates high frequency inputs. The literature survey showed no examples of semi-active vibration control in a parallel platform mechanism which also performs positioning. However, two recent examples of parallel platform mechanisms which are solely built for vibration control through the use of semi-active MR dampers were found (Red Team Too, 2005; Jean *et al*., 2006).

The advantage of semi-active control is that it requires low external power, provides passive energy dissipation if the semi-active part fails, and has inherent stability. A variable damping device using semi-active control would approach the performance of an active actuator in reducing low frequency vibrations while offering several advantages. These advantages include reduced cost by using a simpler actuator intended for only positioning, reduced power requirement, and improved stability.

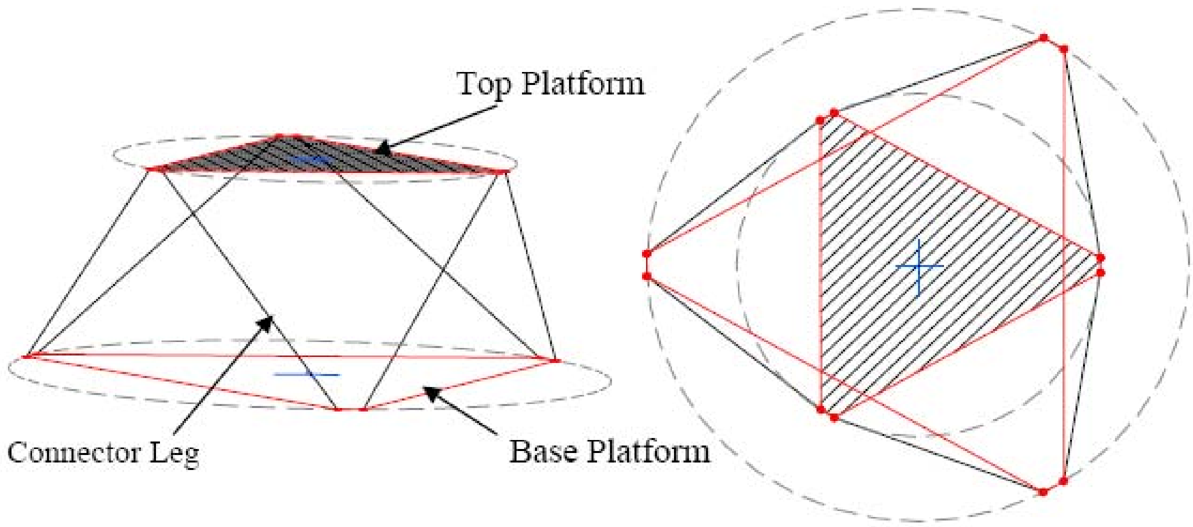


Fig.* 1. *The optimal geometry of the parallel platform mechanism

Several different hexapod platforms were developed by various research groups to provide 6-axis vibration isolation in precision systems. Some of these platforms have larger actuation strokes than others that also give them 6-axis positioning capability. Two groups of these hexapods (Thayer *et al.*, 2002) are as follows:

• **Hard platforms:** These platforms use a stiff actuator, alone or in series with a soft spring. They typically have a very small actuation stroke (~50 μm).

• **Soft platforms:** These platforms use a soft actuator, typically a voice coil actuator. The voice coil actuator is used in parallel with a soft spring and provides far more actuation stroke (1000 μm or more).

The first hard hexapod was made by Intelligent Automation, Inc (Rockville, MD) (figure 2). This hexapod uses a stiff actuator that uses the magnetostrictive alloy, Terfenol-D. Terfenol-D provides accurate linear and oscillatory motion under a magnetic field generated by a low voltage electric current. The actuation stroke is ±127 μm. The struts have no passive isolation capability and use a spring to compensate for the mass of the payload. A load cell measures the axial force of the actuator, and 4 accelerometers are placed on both the bottom and top of each actuator (Geng *et al.*, 1995).

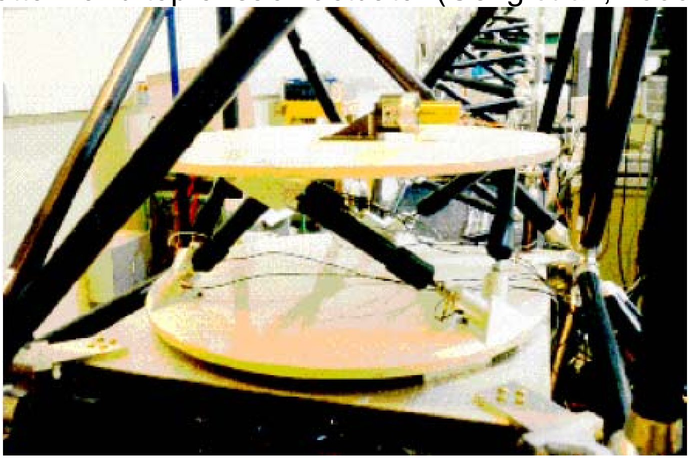


Fig. 2. Hexapod Active Vibration Isolation (HAVI) system from Intelligent

The hexapod designed by Draper Labs (Cambridge, MA) uses piezoceramic actuators. Load cells are used for feedback sensors. This hexapod has no passive isolation capability (Thayer *et al.*, 2002). Harris Corporation (Melbourne, FL) also built a hexapod with piezoceramic actuators. Base and payload accelerometers are used for control. There is no passive isolation and the actuation stroke is ±25 μm (Thayer *et al.*, 2002).

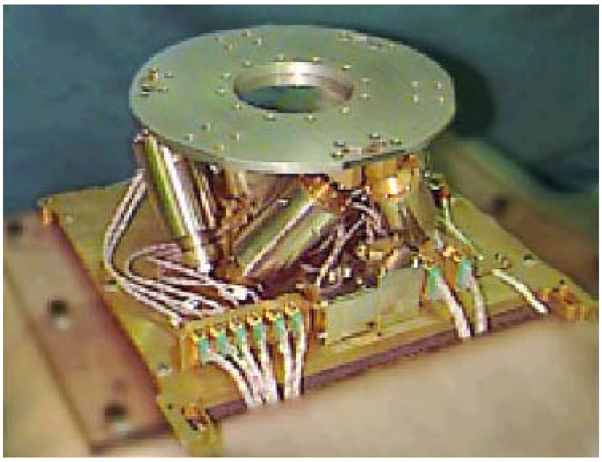


Fig. 3. Hexapod assembly (SUITE) from CSA Engineering (Flint and Anderson, 2001)

CSA Engineering (Mountainview, CA) built two hard hexapods. The first is the Ultra Quiet Platform (UQP). Stiff electromagnetic actuators provide the force, and six geophones are implemented in each strut to provide a single measurement of motion (Anderson *et al*., 1996). The second hard hexapod by CSA Engineering is the Satellite Ultra Quiet Isolation Technology Experiment (SUITE) hexapod assembly (HXA) (figure 3). The SUITE hexapod uses piezoceramic actuators. In series with the actuators are also passive isolation flexures (Anderson *et al*., 2000).

The first soft platform to be reviewed is the Vibration Isolation and Suppression System (VISS) hexapod by Honeywell. The Hybrid D-Strut (figure 4) is the key component of VISS. The hybrid D-strut consists of a voice coil actuator and bellows filled with damping fluid flowing through the orifice between the bellows. Accelerometers are used for feedback and the actuation stroke is ±2 mm (which is an order of magnitude greater than the displacement of any hard hexapod systems). This gives the VISS (as with most soft hexapod systems) low frequency positioning capability. The second soft hexapod (figure 5) was built by the Jet Propulsion Laboratory (JPL) (Pasadena, CA). It uses voice coil actuators and load cells; and relies on external suspension to off-load the mass of the payload from the actuators. It has an actuation stroke of ±0.5 mm. A similar hexapod at the University of Wyoming (figure 6) was also built by JPL. The only difference is that this hexapod has internal springs. This system also has an actuation stroke of ±0.5 mm (Thayer *et al.*, 2002).

Fig. 4. Bipod configuration showing the Honeywell hybrid D-struts

The hexapod by Hood Technology (Hood River, OR) and University of Washington (figure 7) also uses voice coil actuators which have an actuation stroke of ±5 mm. A load cell, an LVDT, and geophones are integrated into the struts as sensors. Elastomer flexures are used for passive damping.

The final hexapod (figure 8) was manufactured by Université Libre de Bruxelles (ULB). Voice coil actuators and load cells are used. Passive damping is not included and external suspension is used to compensate for the mass of the payload. The stroke of the voice coil actuators is ±1.5 mm (Abu Hanieh, 2003).

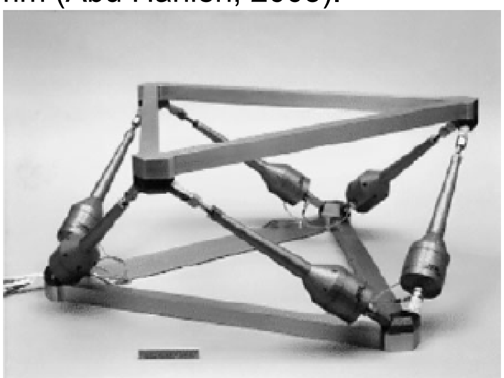


Fig. 5. Hexapod with no internal springs from JPL

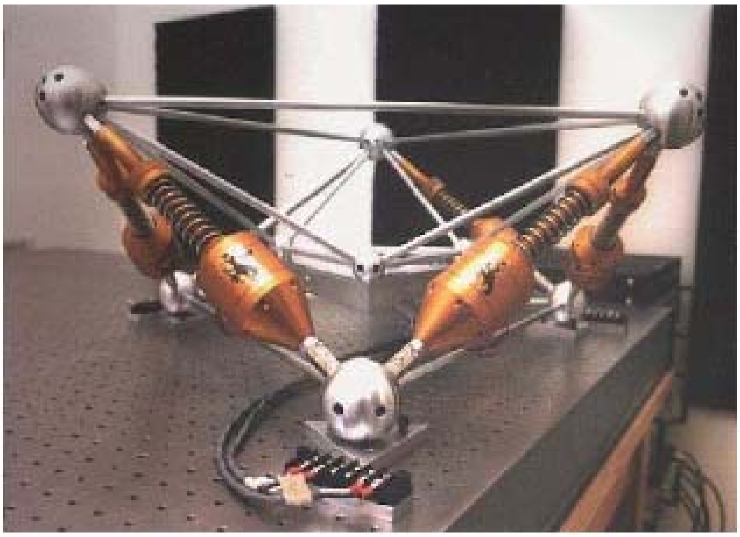


Fig. **6.** ***University of Wyoming/JPL hexapod with internal springs***

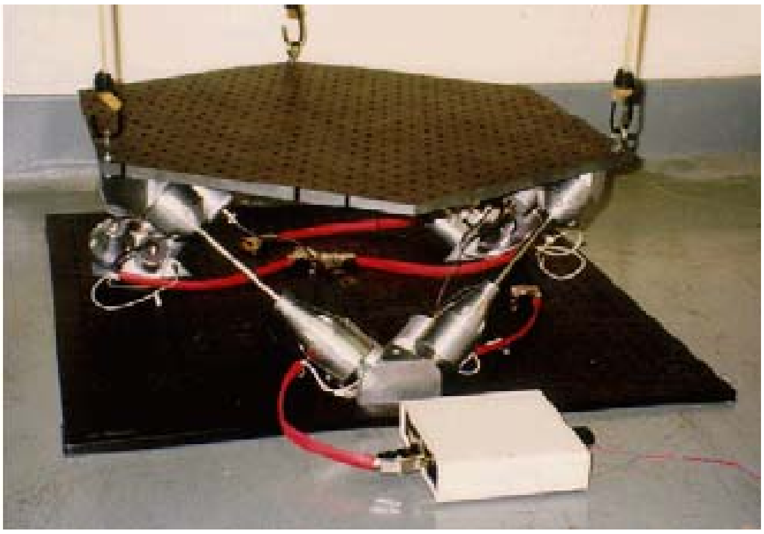
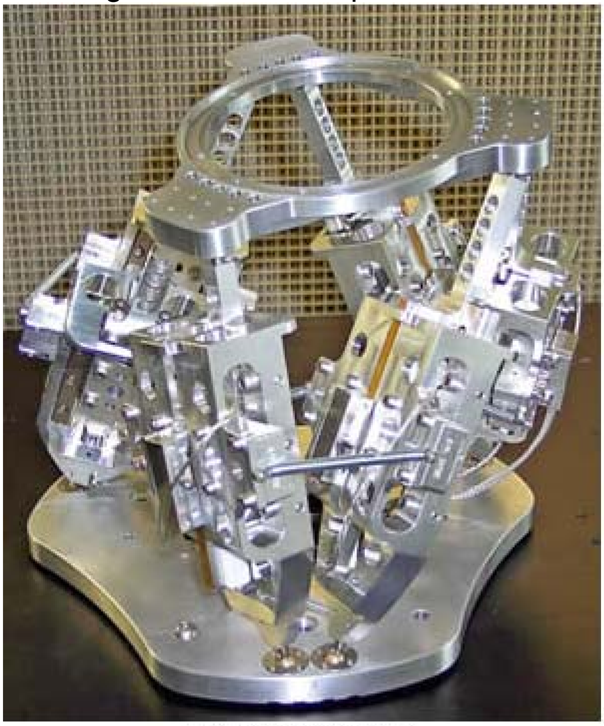


Fig. **7.** ***Soft hexapod from HT/UW (Thayer et al., 2002)***

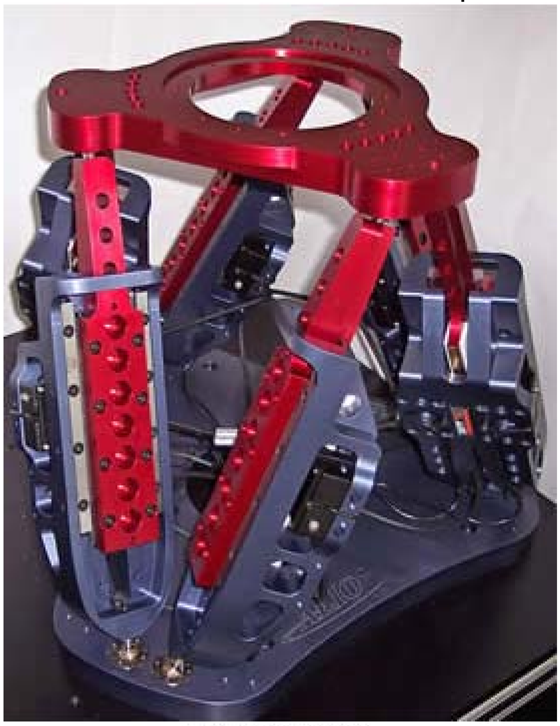
Fig. **8.** ***Soft hexapod from ULB (Abu Hanieh, 2003)***

2. COMMERCIAL STEWART PLATFORM

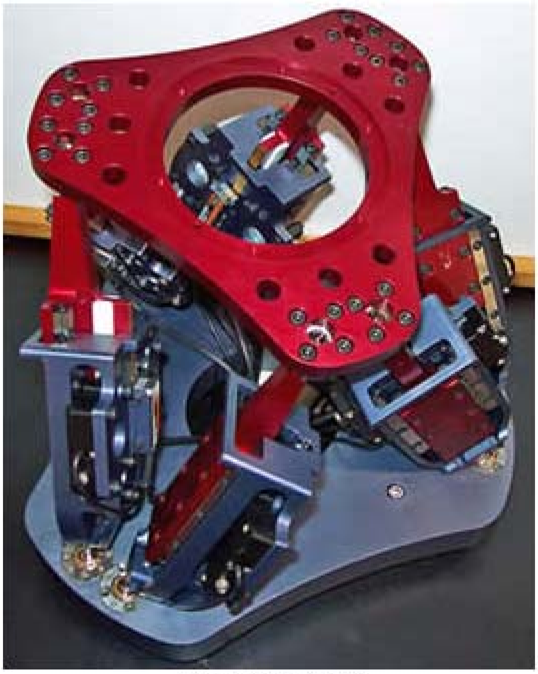
In figure 9, there are presented some representative commercial Steward platforms.



AI-HR2-HV Hexapod



AI-HR8 Hexapod



AI-HR4 Hexapod

Hexapods from ALIO   AI-HR2 Hexapod

Fig.* 9. *Commercial Steward platforms

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