Hexapod Systems for UHV Applications with Active Vibration Damping

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Abstract

Hexapods are widely used for positioning objects in six dimensions of freedom with high precision down to submicron range. For applications in ultra high vacuum atmosphere a hexapod was developed using a driving principle with motors outside of the vacuum atmosphere. The new design further allows the integration of an active vibration damping in all axes.

1 Introduction

In most applications hexapod systems are driven by a motor-spindle combination integrated in the struts, sometimes enhanced by an additional gear system. A commanded position and orientation of the hexapod platform and, thus, of the object mounted on top are achieved by an appropriate change of the strut lenghts using the integrated drive system. However, some design efforts are required to make such a drive assembly compatible for ultra high vacuum. All electrical and electronic parts like motors, sensors or wiring must be sealed to prevent any contamination of the vacuum atmosphere by escaping gases. In some cases even grease is not allowed. Thus, an alternative driving principle for hexapods using struts of constant length is used.

2 Vacuum compatible hexapod system

The structure of hexapods with struts of constant length can basically be divided in two parts, a passive and an active one. The passive structure includes the hexapod platform, the joints and the struts.

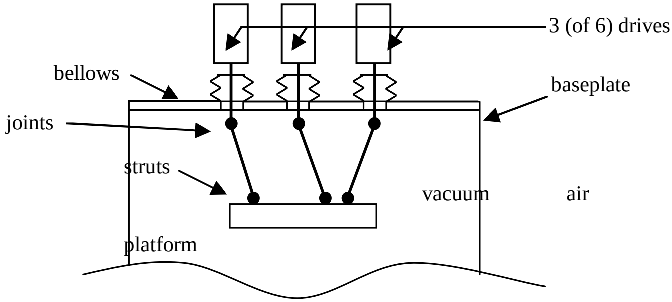

Figure 1: Hexapod with struts of constant length and baseplate separating active and passive substructures [2].

The active structure consists of the drive system with motor, spindle, optional gear, sensors and required wiring. The connection between the two parts is realised by a spindle-driven guided stage moving the base point of the hexapod strut and, thus, changing the position and orientation of the hexapod platform [1]. In Figure 1 this setup is illustrated. Here, the baseplate separates the active and the passive part of the structure. The legs of the hexapod are placed into the vacuum chamber whereas the stages with all required drives, sensors, wiring, grease, and other components are placed outside. An appropriate set-up of bellows enveloping the connection of the stage with the hexapod leg seals the vacuum atmosphere.

2.1 Moving parts in vacuum atmosphere

In this setup the only relative motion in vacuum atmosphere between two bodies is within the joints. If the use of an appropriate grease is not allowed in the vacuum atmosphere hybrid roller bearings consisting of metal housing and ceramic balls can be used. No lubrication is required.

2.2 Height

To reduce costs vacuum chambers are built as small as possible, just big enough to fulfill all necessary requirements. Thus, vacuum pumps can be made smaller and costs can be reduced. Therefore, all systems inside the vacuum atmosphere, too, have to be made as small as possible. With the setup shown in Figure 1 the size of the manipulating system inside the vacuum atmosphere can nearly be reduced by half, simply by placing the active elements outside the vacuum chamber.

2.3 Cooling

In a lot of vacuum applications for high loads or high speed cooling of the drives is required as there is no convective heat flow but only radiative cooling. However, active cooling in vacuum atmosphere using liquids, e.g. in heat pipes, is often not desirable and cooling e.g. by use of heatpipes or Peltier elements demands additional design and cost efforts. With the drive system mounted outside the vacuum atmosphere, both, convective heat flow and radiation often are sufficient for cooling the system.

2.4 Stiffness

Hexapod systems that are used for positioning high payloads have to be very stiff to achieve micron precision. The system stiffness results from both, the stiffness of the single hexapod struts as well as the stiffness of the connecting joints. In the setup shown in Figure 1 inside the hexapod structure there are no weakening connections, such as the spindle-nut-assembly, required. This way, the bodies of the struts can be designed very stiff with very high area moments of inertia. Furthermore, the guided stage as well as the spindle bearing can be made very stiff by appropriate guidings and bearings. For high stiffness in the connecting elements a cardanic structure with axis offset can be used, as presented in [3].

3 Vibration damping

The passive legs of the structure shown in Figure 1 allow the integration of additional piezoelectric actuators making the legs active in a small motion range. Combined with a UHV compatible six-dimensional acceleration sensor mounted onto the hexapod platform, as illustrated in Figure 2, damping of the platform vibrations resulting from an external excitation can be accomplished. Especially the influence of critical eigenfrequencies of the system can be reduced, as depicted in Figure 3.

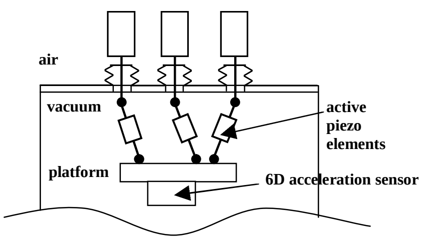

Figure 2 : Extended hexapod structure

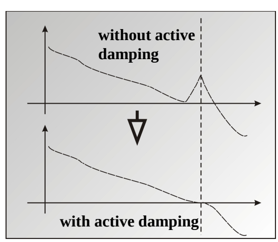

Figure 3 : Influence of active damping

At PI, we designed a hexapod with a structure illustrated in Figure 2, piezoelectric actuators in passive legs of a hexapod structure. With this system a payload of

> 350 kg can be positioned in ultra high vacuum atmosphere with submicron precision down to a repeatability of < 300 nm. A 6D-acceleration sensor based on three MEMS in a vacuum stable package was developed. The corresponding control structure is depicted in Figure 4.

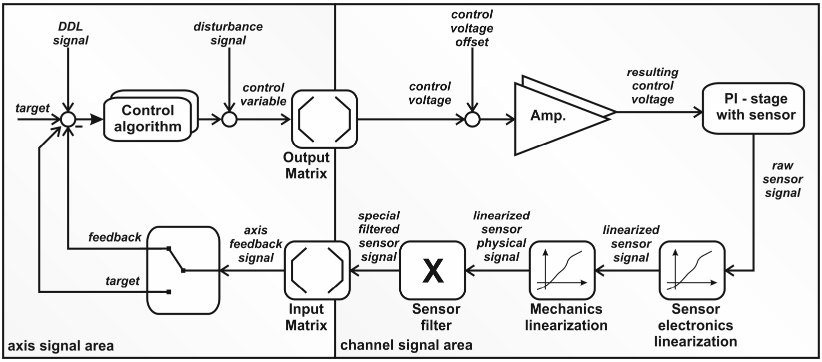

Figure 4: Control structure for 6D vibration damping

In the first steps the non-linearities of sensor electronics and sensor mechanics are taken care of. After linearization the sensor signal is filtered and via an input matrix it is converted from the sensor channel signal area into the axis signal area of real axes x, y, z, rx, ry, and rz. Here, the hexapod position is taken into account as well. The control algorithm based on a PID structure is applied to all real axes. Via an output matrix the control voltage for the piezoelectric actuators for vibration damping is determined. This output matrix correlates with the driving functions of a hexapod with variable length, as described in [2] and [3], to convert the real axes onto the physical drive axes.

To qualify the integrated vibration damping, in zero position the hexapod was excited by a disturbance of rectangular impulses with a frequency of 1 Hz and with an amplitude of 10 µm in y-direction of the hexapod. For excitation the same piezoelectric actuators within the struts are used. The platform acceleration in all six degrees of freedom x, y, z, rx, ry, and rz was measured with the 6D sensor mounted onto the platform. In Figure 5 the results after conversion into the real y-axis are shown. In the upper figure the platform acceleration in y-direction is depicted without active actuators in the hexapod legs, the lower figure shows the platform acceleration with active vibration damping. In the undamped case the duration of the externally excited platform oscillations is longer. The results for the platform acceleration in y-direction after an FFT are depicted in Figure 6. With active vibration damping the influence of the first two eigenfrequencies of the system close to 20 Hz and 45 Hz can be highly reduced. Due to the bandwidth of the 6D-sensor the system vibration damping only works for disturbance frequencies up to 50 Hz. Higher disturbance frequencies are not taken into account for the vibration damping since they are negligible for the hexapod performance for high load applications. Thus, the two frequencies around 70 Hz and close to 100 Hz, resultants from disturbing control feedback, are negligible, too.

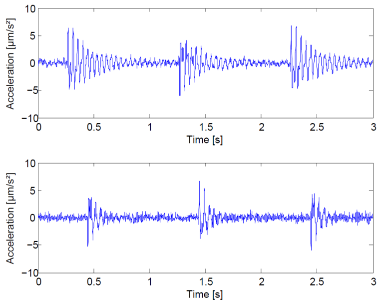

Figure 5: Platform acceleration in time domain without (upper) and with (lower) active damping

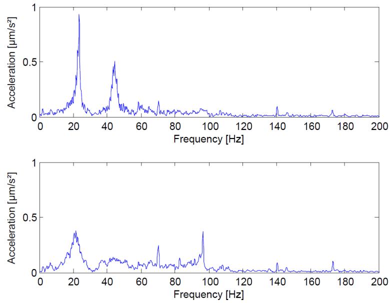

Figure 6: Platform acceleration in frequency domain without (upper) and with (lower) active damping

Conclusion

For application in ultra high vacuum atmosphere hexapods with passive legs of constant length prove useful. All driving components can be placed outside the vacuum. Thus, contamination of the atmosphere can be prevented and cooling of the drives is in most cases not necessary. Furthermore, adding vacuum compatible piezoelectric actuators into the structure of the passive legs an additional vibration damping of the hexapod platform and, thus, an increase of the critical system eigenfrequencies can be achieved.

References

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