HIWIN®

XY Motion System with Active Vibration Control

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Abstract

This paper describes an innovative air-bearing XY motion system with active vibration control for applications where even slight vibrations are intolerable. Accelerometers measure actual vibration levels, and a linear motor counteracts vibrations by generating accelerations in opposite directions to the measured accelerations, resulting in a substantial reduction of overall vibration levels and levels not achievable with traditional passive vibration control.

1. Managing Vibration Strategies for Enhanced Performance

1.1 Negative Impacts of Vibration

Depending on the type of system, there are several reasons why vibrations during motion are undesirable: On helicopters or elevators transporting passengers, vibrations are unwanted because they are uncomfortable or dangerous to passengers. Vibrations can also cause the overloading of critical components and generate fatigue cracks and rupture of these components. In semiconductor processing motion systems, vibrations are undesirable because these processes track the wafer within nanometers. Vibrations during motion will cause deviations from a perfect line when moving between two locations, thus causing the wafer to become unusable and out of specification.

1.2 Passive Vibration Controls

In systems where limiting vibration level is critical, designers typically implement passive vibration control using dampers, shock absorbers and base isolation. These techniques strive to separate the source of the vibration from the rest of the system, minimizing the impacts of vibration.

The system shown in Figure 1 consists of a main frame (A) and a substrate support table (C) actuated via a linear motor (D).

Between the substrate support table and the base frame is a carriage (B) having possible relative motion to the mainframe and the substrate support table. Because the mass of carriage (B) is substantially higher than the mass of the substrate support table, it provides a damping of unwanted accelerations during motion (vibrations). A spring and damper assembly (E) further reduces vibrations.

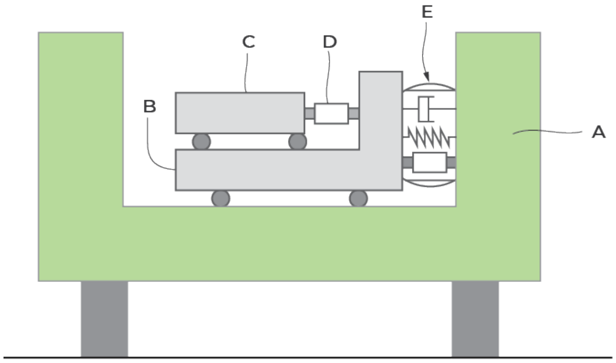

Fig. 1 Passive Vibration Control System

Such a passive system has disadvantages; First, a passive system has limitations in how much vibrations it can eliminate. Secondly, passive vibration damping adds complexity to the design; Dampers and springs add mass. Further, as mass increases, a stronger motor may be needed, which increases cost.

1.3 Active Vibration Control Principle

Active vibration controls overcome the limitations of passive systems. The principle of such a system is to measure accelerations in the directions of interest using accelerometers and then send an acceleration command to an actuator of the same absolute value of the measured acceleration but in the opposite direction, thus canceling out the measured vibration.

Active vibration systems began about 60 years ago and have become more common in the past 30 years. Recently, hardware costs have decreased, and software has become more precise, allowing more applications to leverage vibration control. Known applications of active vibration control include helicopters, elevators, and semiconductor production.

2. Applications for Active Vibration Control

2.1 Helicopters

In a helicopter, the main rotor blades are the source of significant vibrations transmitted to the airframe and passengers. As we have discussed, active vibration control systems have superior efficiency and effectiveness compared to passive systems. Active vibration control achieves better results at variable rotor speeds, while passive systems are predominantly effective for a narrow range of rotor speeds.

Active vibration control is already in use in helicopters. Japanese patent JP3652990B2, “Helicopter Active Vibration Control Device” assigned to Mitsubishi Heavy Industries, describes acceleration sensors attached to the airframe and a rotary electromagnetic actuator attached to the rotor head casing capable of sending counter-accelerations to cancel most vibrations encountered in the airframe. Moreover, the mass of the active vibration system is considerably less than the passive system. This is a significant advantage considering how critical it is to limit the mass of components on an aircraft.

2.2 Elevators

Elevator ride quality is usually measured via the following parameters: vertical vibration, front-to-back vibration, and right-to-left vibration. In 1994, Otis Elevator introduced an active ride control system on pendulum cars, described in US patent 5,308,938.

Entitled “Elevator active suspension system,” the purpose of the invention was to minimize front-to-back and right-to-left vibrations. Linear motor-driven actuators were installed between the roller guides and the car frame generating counter accelerations on the car frame in both directions (front-to-back and right-to-left). The patent describes “A method and apparatus for actively counteracting a disturbing force acting on a suspended elevator car moving vertically in a hoistway” and “A manifestation of the disturbing force such as acceleration is sensed and counteracted. “

Figures 2 and 3 of the patent show a drastic reduction of lateral acceleration vibrations, measured in mg, between a “pendulum car without active suspension,” in other words, a pendulum car with passive suspension, and a “pendulum car with active suspension.”

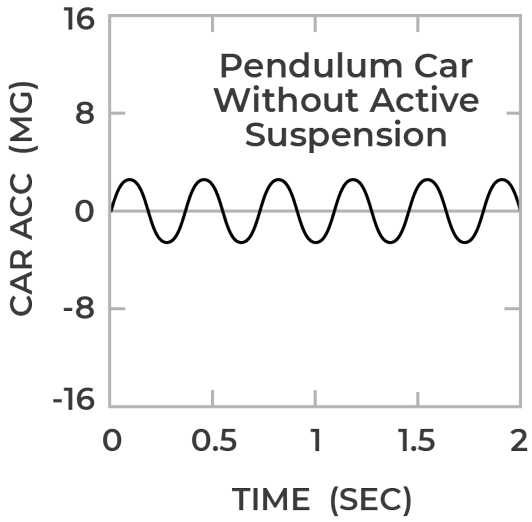

Fig. 2 Pendulum Car Without Active Suspension

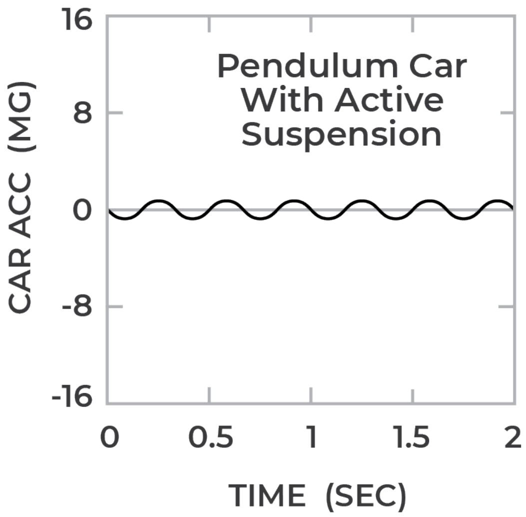

Fig. 3 Pendulum Car With Active Suspension

Active vibration control can be based on electromagnetic or hydraulic technology. It is noticeable that most active vibration control systems prefer using electromagnetic actuators as opposed to other systems.

For example, Japanese patent JP3652990B2 mentions “In particular since the electromagnet 17 is used, there is an advantage that the phase lag is small and the vibration can be effectively suppressed as compared to a vibration control device using hydraulic pressure”, meaning that a hydraulic actuator will be generally too slow when applied to such dynamic active vibration control.

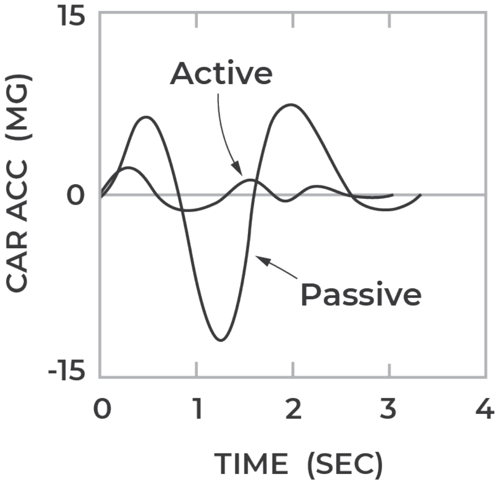

Fig. 4 Comparison of an active and passive suspension system

2.3 Earthquakes

Active vibration control systems became very popular despite the higher cost for the end customer because of their effectiveness. It is utilized as a versatile technology in earthquake engineering to protect buildings and structures, as well as in active seat suspension for heavy-duty vehicles and engine active vibration control in automobiles to improve passenger comfort.

Earthquake seismic active control systems follow the same principles as previously described systems. When an earthquake hits a building, the sensors of the active control system determine the direction and the amplitude of the counterbalance force to be induced in the opposite direction so that the building remains motionless and the structure remains safe. Because these systems are complex and expensive compared to passive systems, they are generally reserved for large-scale projects. Hybrid seismic control systems are also available, combining passive and active seismic control systems.

2.4 Vehicles

A car engine is a major source of vibration in a vehicle. It has a direct impact on the vehicle’s ride, comfort and durability. Conventional vibration isolation systems are passive systems with inherent limitations. Active vibration control systems overcome many of these limitations using electronic controls. The principles remain the same; active vibration isolation systems are closed-loop feedback systems consisting of sensors, controllers and actuators. In most cases, the sensor is a piezoelectric accelerometer that senses the excitation of the engine mount.

The acceleration signal is then processed by the controller. The controller generates a canceling signal that is fed to a power amplifier. The amplifier converts the controller's low-voltage signal to an actuator's current. The actuators, in most cases, are electromagnetic transducers. The force generated by the actuator cancels the primary disturbance signal resulting in near-zero chassis vibration.

2.5 The Semiconductor Challenge

The processing of semiconductor wafers has required increased precision of motion over the past few years because of the continuously decreasing size of semiconductor circuits reaching atomic order of magnitude. These circuits require nanometer-level precision as well as better real-time position tracking, causing the processes to become extremely sensitive to vibrations during motion. Processing semiconductor wafers using extreme ultraviolet (EUV) lithography requires the wafer to track the reticle with less than 3 nanometers position error. Processing speed is also a critical parameter for stages used in the semiconductor industry, as productivity is a concern. Passive vibration controls are not very effective at high speeds. Therefore, the semiconductor industry needs active vibration control.

3. Active Vibration Control Linear Stage for Semiconductor

3.1 HIWIN Diamond Air Bearing System

The Diamond stage from HIWIN is an XY two-axis air-bearing motion system used for the processing of semiconductor wafers or other applications that require overcoming vibration without any deviation.

HIWIN Patent US 9,768,722 describes the design concept and principles of the Diamond stage.

A HIWIN Diamond motor stage is guided in X and Y directions by air bearings over a granite base. Granite is an extremely stable material with minimum surface defects and very low surface roughness. It is a hard material but also has excellent vibration damping characteristics. The top surface of the granite base is usually finished by lapping process, achieving very high flatness characteristics.

Fig. 5 HIWIN Diamond Air Bearing System

Each axis of motion is moving via an ironless linear motor. Ironless linear motors are known to generate much less cogging-induced vibrations compared to iron core motors. Air bearings are devices mounted on a moving part allowing this part to levitate over another surface, typically granite, because of the air pressure built into the air bearing. Therefore, a payload moving on air bearings and driven by ironless linear motors provide the best alternative to supply motion with a minimum amount of vibration to start.

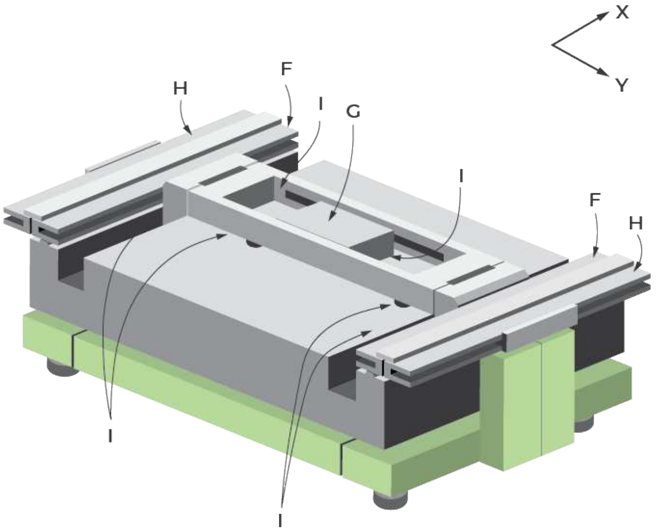

Fig. 6 Air Bearing XY Motion System (Top View)

A closer look at the stage in Fig. 6 and Fig. 7 reveals an XY motion system installed on a granite base. The X and Y axes are guided by a set of air bearings (I). The carriage (G) can hold the payload, typically a 300 mm semiconductor wafer. The stage has two sets of motors, identified as (F) and (H) in Fig. 6, have very different functions. Motors (F) are for the primary axis motion at a given speed and acceleration.

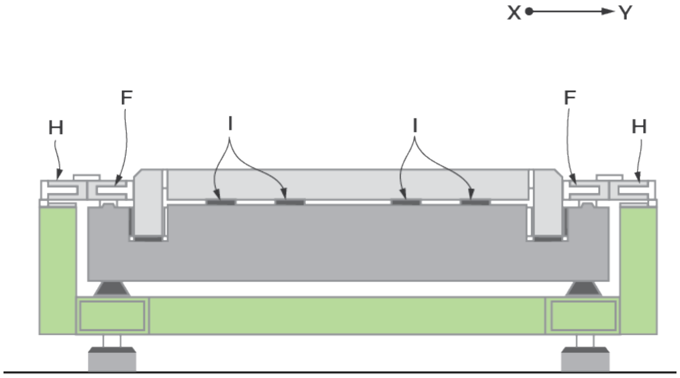

Fig. 7 Active Vibration Control System (Side View)

Motors (H) are used for active vibration control only. They are connected to a different drive using input signal(s) the accelerations registered during motion causing speed and displacement to be uneven and then turning this signal into acceleration commands in the opposite direction to the input signal, thus effectively canceling vibrations in real-time. The improvement in vibration level when the active vibration control system turns on is substantial.

The plots below are showing the vibration level is reduced by 50% when the active vibration control is turned on.

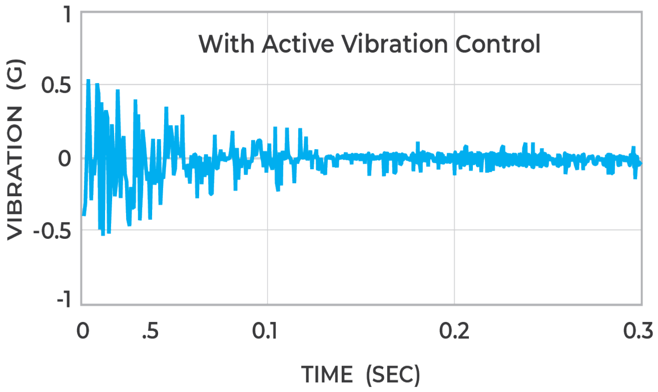

Fig. 8 Vibration Level with Active Vibration Control

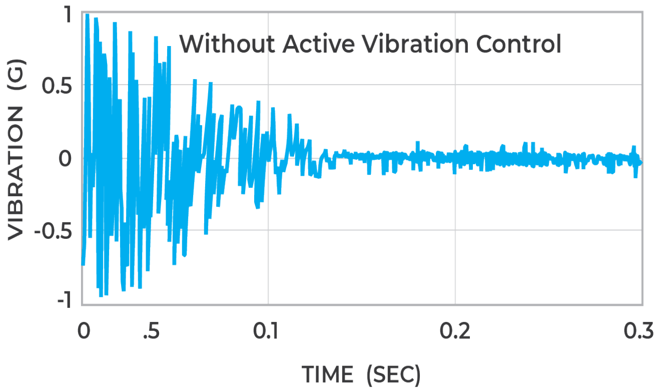

Fig. 9 Vibration Level without Active Vibration Control

The controller for this type of motion system is highly sophisticated because of the high accuracy and tracking requirements. The controller is also supervising the active vibration system by acquiring inputs from the accelerometers and sending these to the drives after they have been reformatted into motion commands. Because the vibration control must happen in real time the response time of the controller is critical and must be as short as possible, requiring the most advanced hardware available.

6. Conclusion

Countering vibration is achieved by either passive mechanical methods or active electronic technology. Passive technology may be less expensive at the component level than active, add mass, reduce system life, complicate designs, and are limited to substantial vibrations. Active vibration control is the best selection for applications that require highly variable countermeasures vibration control at high speeds. Air-bearing granite tables are the best choice for any application where nanometer vibration control is required.

As a solution against vibration, HIWIN's Diamond linear motor stage has several differentiating features:

1. Ironless linear motor creates less vibration than its iron-core equivalent.
2. Air bearings on a granite base prevent vibration when the moving parts glide on air over a perfectly smooth surface.
3. Dedicated active vibration control system to counter any vibration that naturally occurs from the movement itself.

For more information about HIWIN's Diamond linear motion stage with active vibration control, or any HIWIN motion control product, please contact us.

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