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Inertial vibration cancellation for floor fields and stiff machine pedestals

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Abstract
A method for vibration cancellation is described which works favourably at the floor of semiconductor factories, by decreasing the vibration level with a factor 3-5 in the 10 – 100 Hz bandwidth. The method has the advantage that lower vibration levels can be achieved without loss of stiffness on the stiff factory floor. Dynamic and control aspects of the method are discussed and an example of what can be achieved is presented.

Keywords: vibration control, vibration isolation, vibration cancellation, damping, stiffness, compliance, FEM, building dynamics, modal measurements, control system, feedback control, semiconductor factories

1. Introduction

Vibration control can be categorized by looking at the location where it is done or by the method that is used. Locations are: at the source, somewhere in the path and at the user: presumably a precision machine. Methods can be: elimination, isolation and counteracting. Elimination can be removing the vibration source or removing the path between source and precision machine. Passive isolation can be used either at the source or at the precision machine. Active isolation is mostly used to isolate the precision machine from the vibrating floor by use of a weak suspension combined with actuators to suppress motion. Counteracting means to apply forces to a vibrating floor or machine, that cancel out the vibration. Passive counteracting can be done with a tuned mass damper, which is limited to suppress vibrations in a fixed, narrow frequency band. Active counteracting or 'cancellation' implies that sensors and actuators are added for better performance. This article describes a new method of active cancellation which can work on a broad bandwidth, preferably somewhere on the building close to the precision machine. The method was initially developed for semiconductor fabs but can also be applied elsewhere.
Paragraph 2 describes the situation in semiconductor factories. Paragraph 3 contains a general description of the cancellation system, EQUALIZER, developed by MECAL. Paragraph 4 discusses an example project with the cancellation method. The last paragraph gives a summary of the described method and of the example application of this method.

2. Situation in semiconductor factories

2.1. Fab design

The fab design is generally optimized to get a low vibration level where it is needed. The cleanroom factory itself, where the vibration sensitive machines are located, is placed on a separate, stiff, foundation. Secondary equipment that causes a lot of vibrations, such as pumps, are generally placed in the sub-fab. These separate foundations ensure that the transfer for forces of the sub-fab equipment to the stiff fab floor is minimal (elimination of path).

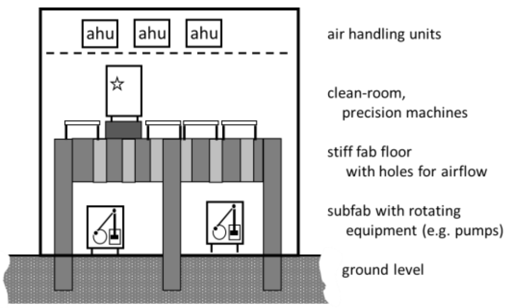

Figure 1. Schematic outline of a semicon fab

2.2 Precision machines specification

Vibration specifications are anywhere between VC-F (1.5 μm/s) for very special equipment (microscopes) to VC- B (25 μm/s). Vibration levels are proportional to the forces acting on the structure and the compliance of that structure[1]. High stiffness of this floor is necessary since it supports fast moving equipment like wafer scanners, that can put considerable dynamic loads on the floor. Stiffness specifications are in the order of 1-2E8 N/m but tend to go up for newer equipment for faster production of even smaller computer chips.

2.3 Problem with active vibration isolation

When the vibration level is too high for a specific machine, an active vibration isolation pedestal can be used. Vibrations can be brought down with a factor 3 to 100 over a broad frequency range (1- 100 Hz) in all directions. In practice, results can be less favourable due to the inherent lower stiffness of an (active) isolation pedestal compared to a pedestal which is stiffly connected to the fab floor. The vibration level due to forces from the machine itself will be much higher due to the decreased stiffness.

3. Inertial vibration cancellation

To decrease vibration levels without loss of stiffness, MECAL developed an inertial vibration cancellation system called EQUALIZER. The system consists of one or more inertial actuators, each paired with an inertial sensor and a feedback control system. Based on the vibrations measured by the sensors, the control system precisely determines the forces applied to the floor by each inertial actuator. The feedback control loop continuously adapts these forces to minimize the floor vibrations it measures. It is intended to be used on the stiff fab floor or on a machine pedestal which is stiffly connected to that floor. The damper works in one direction, typically the vertical, and more sensor/actuator pairs can be used to cover a larger area.

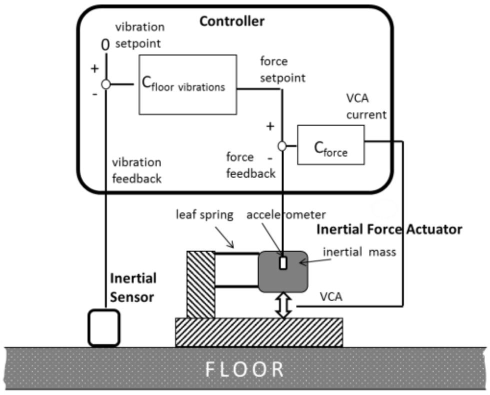

Figure 2. Schematic view of EQUALIZER

At frequencies below the natural frequency of the inertial mass (figure 2) the performance is limited by the force output of the VCA and by sensor noise. MECAL developed an inertial sensor with noise levels well below 1e-8 m/s at 1 Hz (ref. [2]), and minimized the natural frequency of the inertial mass. Subsequent internal modes of the actuator and sensor that are visible in the control loop are much higher than 500Hz. This ensures that the equalizer operates effectively between 10 Hz and 100Hz.

Ultimately the system performance depends on the dynamics of the floor and the fixed pedestal. A pedestal with internal stiffness much higher than the inherent floor stiffness, such as the MECAL Machine Support Frame (MSF) is favourable.

A typical example of open loop transfer (controller and EQUALIZER on a fab floor with MSF) is shown (figure 3). It shows a control setting for maximum cancellation at 30 & 59 Hz where vibration peaks do occur.

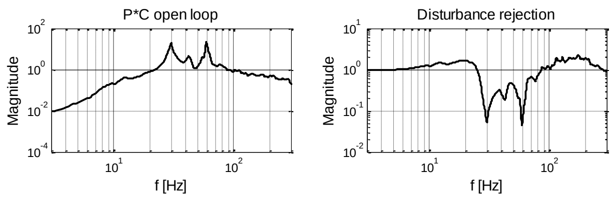

Figure 3. Open loop transfer function and disturbance rejection

4. Example application of the cancellation method

4.1. Problem description

A new precision machine is projected in an existing semiconductor fab. The machine has stringent vibration and stiffness specifications. The stiffness of the existing fab floor is a factor 2 too low and the vibration spec is exceeded by a factor 3 between 25 and 60 Hz, caused by external sources. Removal or isolation of the vibration sources was not an option due to practical reasons. The stiffness specification for the machine ruled out the possibility of an active isolation system.

4.2. Approach

To make the factory suitable for the precision machine MECAL started the following approach:

An extended site-survey has been performed with modal measurements of the entire floor field.

The building has been modelled in FEM and the model is tuned to the modal measurements.

A structural stiffening solution has been designed that improves both the floor stiffness and the dynamics seen by the cancellation system. The stiffened floor has been added to the FEM model as well as a crude dynamic model of the machine. A dynamic Matlab model was extracted from this to evaluate the performance with the use of the EQUALIZER vibration cancellation system.

With the aid of the dynamic model the optimal number and placement of the sensor actuator pairs could be determined as well as the expected reduction of the vibration levels.

4.3. Results

The result shows vibration levels everywhere on the pedestal within the specification and a reduction of a factor 10 locally and a factor 3 globally, bringing the vibration peaks within the machine specification.

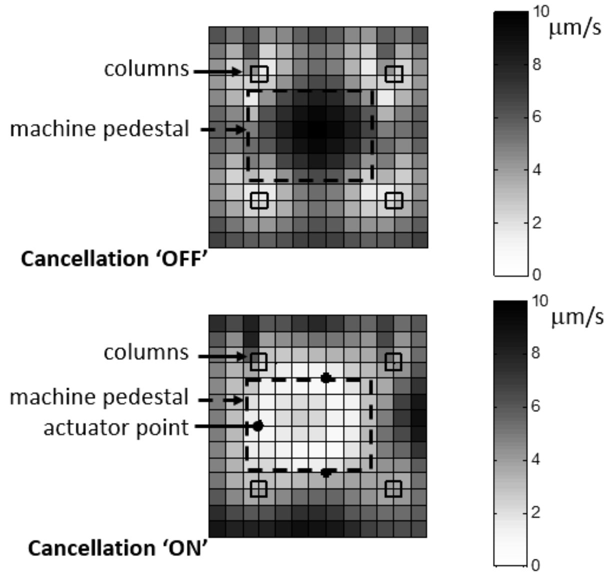

Figure 4. Results for floor vibration reduction

5. Conclusion

A method for active vibration cancellation has been described suitable for semiconductor factories. Cancellation of a factor 3 can be achieved in the frequency range of 10 to 100 Hz. The major advantage of this method opposed to vibration isolation is that the stiffness is not compromised. This is crucial for machines which produce large forces such as wafer scanners.

An example project has been described where this method, in combination with a floor stiffening design, is used to achieve both increase of stiffness and decrease of vibration levels. The approach consists of modal measurements, FEM modelling, structural design, dynamic modelling and the use of the MECAL EQUALIZER vibration cancellation system. Results show a factor 2 increase in stiffness and a factor 3 vibration reduction of the relevant vibration peaks over a large floor area.

References

[1] Gordon C G 1987 'The Design of low-vibration buildings for microelectronics and other occupancies' *SPIE Vol 732*.

[2] Bank S Rijkers R van Seggelen J Bakker B 2015 'Design and implementation of an active vibration isolation solution for a ceiling mounted microscope' Euspen 2015