Mechanical Vibrations: Its Effect on Assembly Equipment and Methods of Characterization

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Abstract
As electronic packages keep shrinking in size, high-speed high-accuracy package assembly equipment are becoming more sensitive to mechanical vibrations. Alignment, positional and pick & place accuracy can be compromised during high speed operation due to sensitivity to mechanical vibrations which are generated within the assembly equipment, as well as from the floor and neighboring machines. Vibrations can also affect process yield as a result of diminished accuracy. Semiconductor package manufacturers are under constant pressure to increase output, at the same time are challenged by tighter alignment accuracy requirements.

This paper describes the methodology used to characterize the vibration response of manufacturing equipment under vibrating floor environment, and that of the manufacturing floor under vibration induced by operational equipment. Case study of pick & place equipment shows significant differences in vibration levels were found in different building facilities and factory floor conditions. Also described in the paper is reason why a standard/specification is needed for purchased assembly equipment. Industry standard needs to be developed that can help specify how much vibration can be transmitted from the machine to the floor, and how much internal and external vibration the machine should be able to withstand without affecting performance or quality and reliability. Examples of possible solutions that manufacturers and equipment suppliers can adopt to meet future needs for precision high-speed placement equipment are also discussed.

Introduction
Mechanical vibrations in semiconductor equipment are essentially caused by energy generated and conserved in the system. Equipment can be treated as a summation of several simple spring mass damper systems. Energy is generated either by periodic movement of machine parts, or random motion event internal or external to the machine. That energy is transferred back and forth as kinetic energy in mass and potential energy in the spring, which causes the equipment to vibrate. System will continue to oscillate until damping dissipates the energy and brings it to rest. In a lightly damped system when the forcing frequency nears the natural frequency, the amplitude of the vibration can get extremely high. This phenomenon is called resonance and that natural frequency of a system is often referred to as the resonant frequency. If resonance occurs in a mechanical system such as assembly equipment, it will be harmful to the performance of the equipment.

Vibrations and Assembly Equipment
Semiconductor manufacturers have to traditionally meet the facilities and building specification imposed by manufacturers of vibration-sensitive semiconductor equipment. Equipment manufacturers specify limits on environment in order to meet the performance specification, and not be affected by vibrations. Facility engineers have to ensure that building design minimizes the sources of vibrations. Widely accepted generic criterion curves are developed [1,2, 9] to address the need of sensitive semiconductor equipment. Tools that use Cartesian robots for alignment use dynamic forces to achieve accurate positioning. These forces if not resisted by the machine structure can generate vibrations.

Vibration isolation is the process of isolating an object, such as a piece of equipment, from the source of vibrations. Passive vibration isolation system include a mass, spring and damper. They are typically used for isolating higher frequency vibrations. Active vibration isolation systems contain along with the spring, a feedback circuit which consists of a piezoelectric accelerometer, a controller, and an electromagnetic transducer. The vibration signal is detected and processed by a control circuit and amplifier. Then it feeds the electromagnetic actuator, which amplifies the signal. As a result of such a feedback system, a considerably stronger suppression of vibrations is achieved compared to ordinary damping. Passive systems are generally used for low frequency vibration isolation.

One of the key aspects of semiconductor equipment design is to perform vibration analysis upfront during the development process in order to predict when resonance may occur, and to determine what steps to take to prevent it from occurring. Vibration analysis should be done in relation to the applicable criteria as far as possible. If thorough engineering work is invested during development (such as failure mode and effects analysis (FMEA) related to machine vibration, modal analysis, isolation solutions considering interaction with different floor conditions), then costly redesign and delays can be avoided down the road.

Facilities and Equipment Criteria

There are some standards and practices for classification of vibration environment for sensitive equipment (e.g. BBN, IEC 60721, ISO 8569) but they are not very compatible [6]. As an accepted practice in semiconductor industry, limits on vibrations of floors that support precision equipment may be stated in terms of several different measures: maximum velocity or acceleration; root mean square (RMS) velocity or acceleration; or maximum velocities or accelerations at given frequencies [1]. Currently some specifications include the limits on the floor vibration based on ISO 2631 [4] specification. Figure 1 and 2 show the generic facility criteria (adapted from Reference 9). Some equipment may be affected by short-duration transient disturbances, whereas others are affected by periodic vibrations.

Facility Equipment or Use	Velocity Limit* µm/s	Velocity Limit* mils/s
Ordinary Workshops	800	32
Offices	400	16
Residences, Computer Systems***	200	8
Operating Rooms, Surgery, Bench Microscopes up to 100×, Laboratory Robots	100	4
Bench Microscopes up to 400×, Precision Balances, Metrology, Class A Equipment**	50	2
Micro and Neuro-Surgery, Bench Microscopes at Greater than 400×, Optical Equipment on Isolation Tables, Class B Equipment**	25	1
Electron Microscopes at up to 30,000×, Microtomes, Magnetic Resonance Imagers, Mass Spectrometers, Class C Equipment**	12	0.5
Electron Microscopes at Greater than 30,000×, Cell Implant Equipment, Class D Equipment**	6	0.25
Unisolated Optical Systems, Class E Equipment**	3	0.13

* Corresponds to Figure 1 curves from 8-80 Hz. (1 mil = 1000 µin.).

** Equipment typically used in microelectronics and photolithography:
- Class A – Inspection, probe test, and other manufacturing support equipment
- Class B – Aligners, steppers, photolithography tools for line widths of 3 µm or more
- Class C – As above, for line widths of 1 µm
- Class D – As above and electron beam systems, for line widths of 0.5 µm
- Class E – As above, for line widths of 0.25 µm or more.

*** Curve of Figure 1 corresponds to standard mean whole-body threshold of perception.

Figure 1 – Generic Facility Criteria

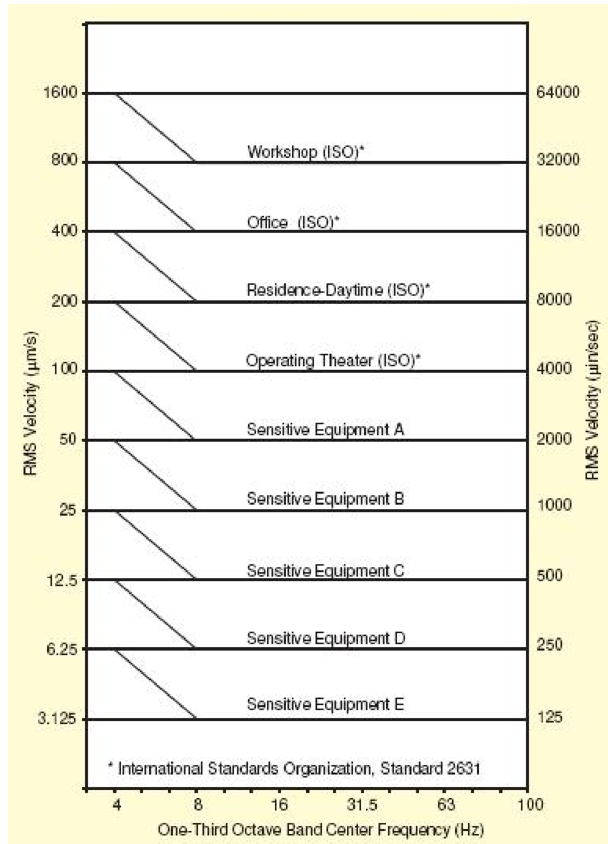

Figure 2 - ISO Generic Facility Criteria

Note that in Figure 1 criteria are stated in terms of root mean square (RMS) velocity in 1/3 octave frequency bands and that the given curves extend from 4 to 80 Hz. Outside of this frequency range, greater vibrations are assumed to be acceptable. For equipment that includes internal vibration isolation with associated natural frequencies in the 1-2 Hz range, it has been suggested that the horizontal portions of the curves be extended down to 1 Hz.

For relatively constant environment it is generally adequate to measure the “energy average” vibration levels. Levels can be measured at multiple locations, and over long period of time (e.g. 10 minutes), and statistically summarized. In cases where a site is impacted by short-term transient events, such as a WIP cart or a person walking by the site, it is necessary to measure the “maximum RMS” (on some signal analyzers called “peak RMS” or “peak hold”) level to adequately characterize the transient impact [2].

Case Study

Chip and component attach Equipment for package assembly: Typical alignment accuracy requirement for semiconductor assembly placement equipment is in few micrometers. In high volume manufacturing, these precision machines have to pick up silicon die (or a component) and place it on the package with very high accuracy. In order to meet throughput targets, the machine has to pick up, accelerate to the desired location, and settle to a position very quickly. If energy conserved in the system is not quickly dampened, the increased settling time will have a negative impact on machine output. Vibration energy can come from several sources – vibrations internal to the equipment which is not damped out quickly, and/or external vibration coming from the floor.

In an effort to understand the effect of mechanical vibrations on equipment performance, engineers at Intel Corporation acquired vibration measurement metrology which included accelerometers, analyzer, and software for data analysis as shown (Figure 3). Two different types of accelerometers were used: low frequency seismic accelerometer for floor vibration measurement (Figure 4), and general purpose high frequency accelerometer (Figure 5) to be mounted on the equipment.

Figure 3 - Signal Analyzer

Figure 4 – Seismic Accelerometer

Figure 5 – High Freq Accelerometer

Four test scenarios were considered (1) Ambient/floor vibration measurement per the generic criteria described in Facilities and equipment criteria paragraph above (2) Vibrations emitted by the equipment during production into the floor (3) Vibration signature of the same equipment in two different floor conditions (4) Compare effectiveness of vibration isolation upgrade on the equipment. Seismic accelerometer was placed next to one of the foot of the tool for all the measurements on the floor. In scenario 3 additional sensor were also mounted on the tool frame and placement head. Response charts with frequency spectrum were plotted as shown in figures 6 through 9.

For scenario (1), ambient floor vibration was measured for facility#1 with methodology very similar to the facility and equipment criteria; except RMS velocity was captured in the range of 1 to 100 Hz. Equipment was not in production mode, hence not moving or not inducing any vibrations in the floor. Figure 6 shows an example of the measurement taken with Seismic accelerometer. RMS velocity of 0.4733 mil/s indicates that the floor in this example meets the facility criteria for class C equipment mentioned in Figure 1

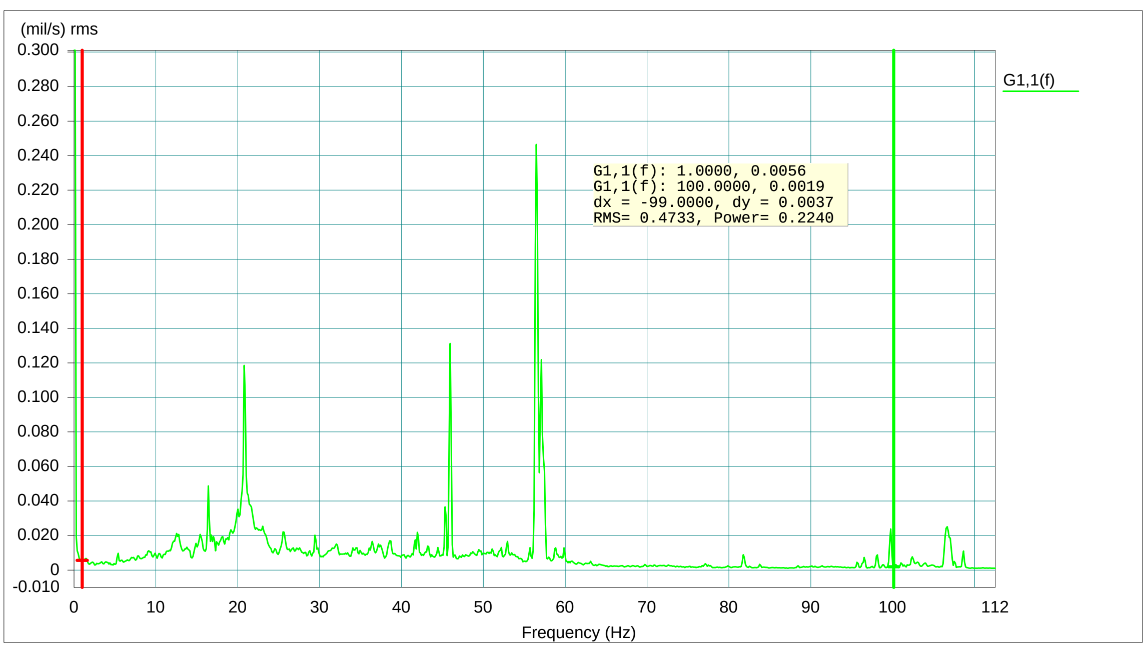

Figure 6 - Floor velocity (mil/s) between 1 and 100 Hz, equipment in production mode: scenario (1)

For scenario (2), the test objective was to compare the RMS velocity measured at the same location as in scenario (1) above, but now with equipment running in production mode. During production mode, the gantries of the pick and place equipment are accelerating and decelerating at high speed, causing vibrations in the frame of the equipment which are transferred to the floor. Seismic accelerometer was placed next to one of the foot of the tool for all the measurements on the floor and RMS velocity was captured in the range of 1 to 100 Hz. For example in Figure 7, it is seen that when these particular machine is turned on in production mode, the RMS velocity at the same location on the floor changed to 0.900 mil/s. This indicates that the equipment if placed close to other class C equipment, could affect its performance.

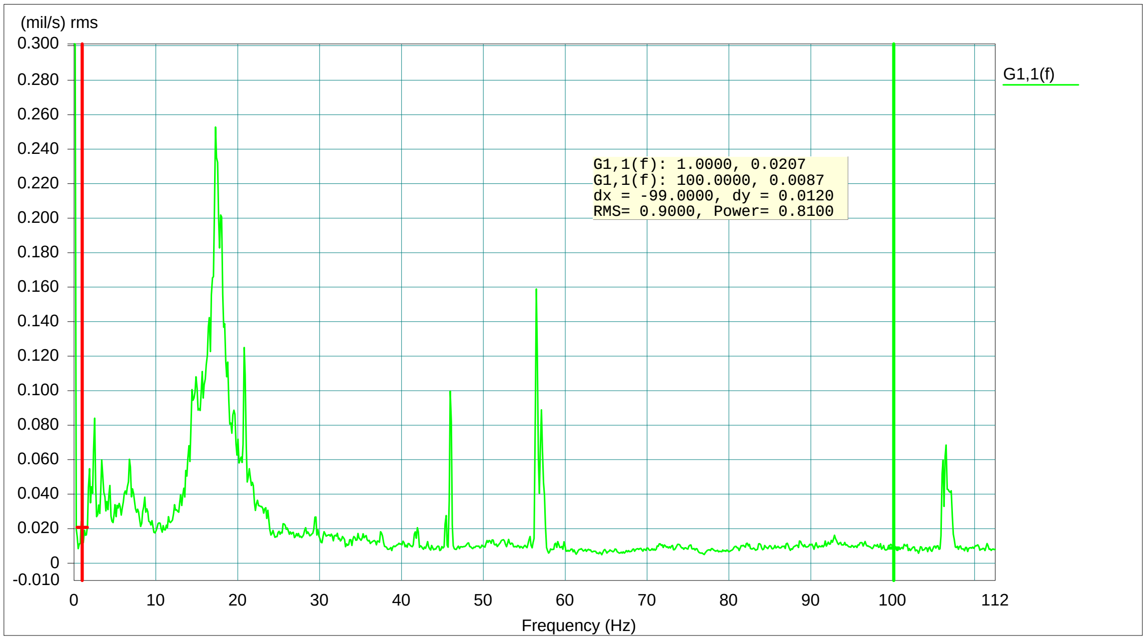

Figure 7 - Floor velocity (mil/s) between 1 and 100 Hz, equipment in production mode: scenario (2)

For scenario (3) the same equipment was relocated on 2nd floor of another site (facility #2). In order to understand the vibration signature of the equipment at this location, seismic accelerometer was placed at same distance from the foot of the equipment. High frequency accelerometers where also mounted on the frame of the machine (data not shown in this paper). Measurements were collected using the same methodology in the previous scenarios, while the equipment was running in production mode. In the example in Figure 8 it is seen that RMS velocity in the 1 to 100 Hz range is almost 4 times compared to the data collected at facility #1.

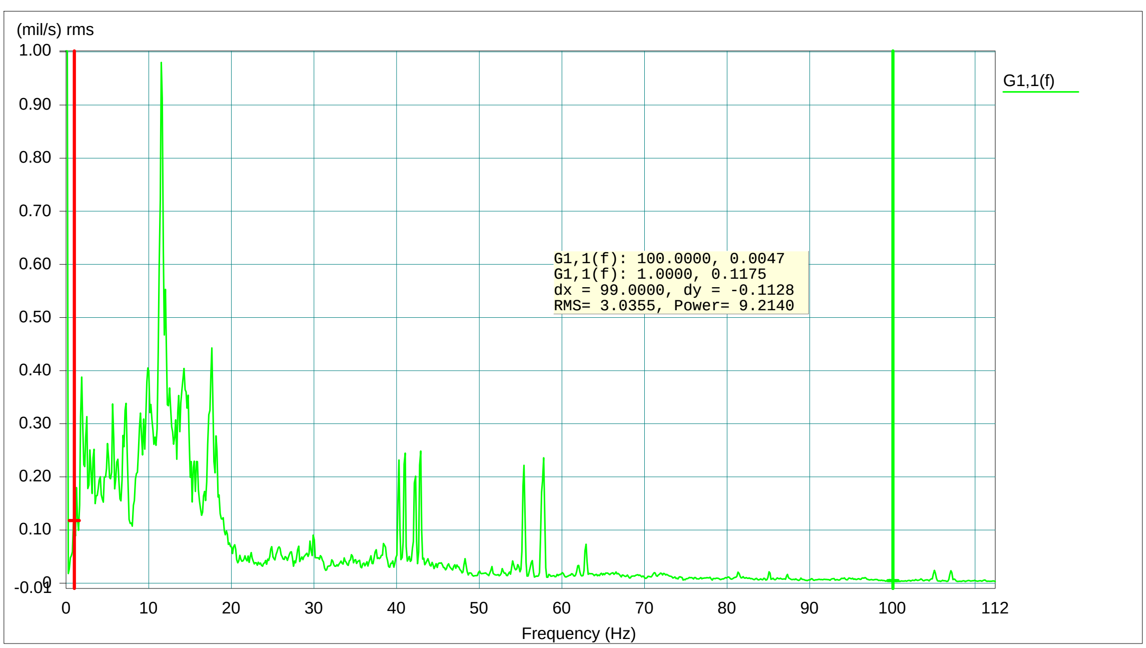

Figure 8 - Floor velocity between 1 and 100 Hz, equipment in production mode: Facility #2

Approach similar to the generic criteria was extended to scenario (4) to understand the effectiveness of vibration dampener upgrade to the manufacturing equipment. A comparative approach was used to understand if the upgrade had reduced the energy released by the equipment into the floor. In Figure 9 G1,1 represents the vibration response of the floor with equipment running in production mode with new dampener upgrade compared to vibration response before the upgrade. The RMS vibration energy transmitted to the was reduced by approximately 14% as a result of this improvement.

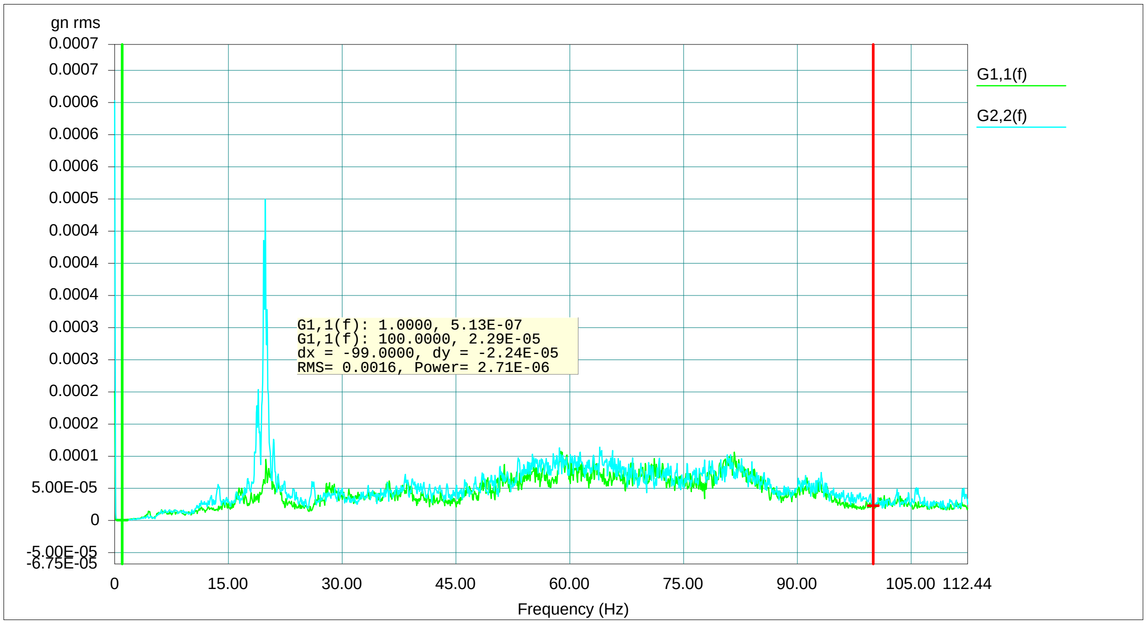

Figure 9 - Comparison of vibration signature with and without dampener upgrade

Note that same 1 to 100 Hz frequency range was used, but RMS unit was acceleration (g), which is different from the generic criteria used in scenarios 1, 2 and 3 above.

Summary and conclusion

Mechanical vibrations can negatively affect the performance of precision electronics assembly equipment, especially for high speed high accuracy manufacturing equipment. Quality, reliability, or factory output can be compromised as a result of sensitivity to vibrations. Adding vibration isolation and damping can significantly reduce the magnitude of the vibration. Also, the magnitude can be reduced if the natural frequency can be shifted away from the forcing frequency by changing the stiffness or mass of the system during design (this can be achieved through modal analysis). If the equipment design cannot be changed, perhaps the forcing frequency can be shifted e.g. changing the acceleration profile of the machine which is generating the force.

Criteria, similar to one described in case study above, needs to be established for packaging and assembly equipment so that a standard methodology is used to characterize vibrations (a) coming from the floor on which the equipment needs to work with effectively, and (b) generated and transmitted from the equipment to the supporting structure such as floor or wall.

References

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