Vibration Design of 300mm Wafer Fabs

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INTRODUCTION

The semiconductor industry is experiencing the transition from 200mm to 300mm fabs. With a number of 300mm fabs now on-line, and many more in the construction and start-up stages, a discussion of 300mm fab design is pertinent. Vibration is an important concern in fab design and construction because many items of precision equipment (or "tools") in a fab have environmental requirements that must be met in order to perform satisfactorily; in many cases these requirements include limits placed on vibrations.

The transition from 200mm to 300mm fabs poses a significant challenge for fab vibration design because of the increase in wafer diameter, more advanced tools, more sophisticated process technology, and increased automation. More than ever, a multi-discipline approach to vibration control is called for in fab development.

This paper presents an integrated vibration design process for a 300mm fab. This design process, which has been applied in the design of several 300mm fabs, includes

1. Design Criteria,
2. Site Survey,
3. Foundation Design,
4. Layout Design,
5. Structural Design,
6. Mechanical Design,
7. Construction Documents and Administration,
8. Structural Evaluation, and
9. Final ("as built") Evaluation

DESIGN CRITERIA

Generic Vibration Design Criteria

The tool vibration requirements generally vary from tool to tool, both in amplitude and format for analysis and/or measurement. Generic vibration criteria, therefore, have gained popularity because they avoid the trap of having to design for a specific tool, when that tool might be replaced in a few years by something similar, but with slightly different requirements.

Ungar and Gordon (1983) proposed the generic vibration criteria shown in Figure 1 for vibration-sensitive processes and facilities. The criteria consisted of four velocity spectra denoted as curves A through D, and were based upon published manufacturers' environmental requirements of the time, plus some engineering judgment. As equipment became more vibration sensitive, a new curve E was added, and they were adopted into an industry standard (IEST, 1994) and several handbooks [*e.g.*, ASHRAE (1999)].

Ungar, Sturz and Amick (1990) proposed a change to be implemented at frequencies below 8 Hz when tools contain internal pneumatic isolation. This is typically applied to curves D and E.

"As Built" Conditions

It is our normal practice to design a facility to one of the standard vibration criterion (VC) curves for "as built" condition. With the facility in the "as built" condition (as defined by the Institute of Environmental Sciences and Technology), linear average vertical and horizontal vibration velocities, measured directly on the structural floor at multiple randomly selected locations shall, in each one-third octave band between 8 Hz and 80 Hz, not exceed the velocity level defined by the horizontal portion of the VC curve (e.g., 3.2 μm/s rms for VC-E) at the "mean plus one standard deviation value" of collected data. Great care in the hookup design and tool installation is required in order to maintain the "as built" criteria with the fab in the operating condition.

The "as built" state is that in which cleanroom certification itself is usually carried out. It represents the "typical" state of the building and its operating mechanical infrastructure, without the influence of user-supplied equipment (tools and support systems). It is generally our intent (and that of IEST in cleanroom certification) to represent the building in its "typical" state prior to installation of tools and contamination by personnel activities, rather than the absolute best the space can do but never provide (as would be the case if measurements were made without mechanical systems operating).

The generic vibration criteria (VC curves) are based in part on the environmental vibration specifications provided by tool manufacturers. These environments are expected by the tool-maker to be present at the time the tool is installed. Thus, a facility designed

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such that its vibration criterion is met in the "as-built" state is the one most likely to meet tool-makers' specifications.

Accelerance Criteria

The advent of the photolithography scanner tool introduced a new design parameter termed "accelerance," shown in Figure 2, into the design of semiconductor fab process floors. The purpose of this parameter is to limit tool movement generated by the inertial forces involved in moving the reticle and wafer stages within the tool. It is critically important in the 300mm fab design to take this parameter into account.

SITE SURVEY

It is rarely possible in a practical sense to isolate a building from a vibrationally "noisy" site. Therefore when a site is selected to carry a building that will house vibration-sensitive tools and processes, it is generally essential that the site vibration environment be surveyed so that the combined effects of transportation (roads and railways), construction, local industry, etc. can be quantified on the site.

In the event that site measurements equal, or exceed, the required performance then the site must generally be rejected for the reasons given above, unless it can be shown that cost-effective methods of site remediation are available.

In the selection process the future use of the site and possible developments around the site must be considered. For example, in one current case there are plans to construct a high-speed rail link along one side of the site. We have been able to show that, because of soil and building characteristics, the adverse effects of the railroad will be attenuated to some extent. On that same site the soil conditions are such that restrictions must be placed on construction methods used for future site developments.

In the case of all sites, long term plans for zoning and highway development must be considered since one must avoid the possibility that the long-term use of a site may be threatened by developments in zoning and transportation.

The acceptability of a site from a vibration standpoint is dependent on 1) the nature, source, frequency, and amplitude of the site ambient vibration; 2) the facility building options; and 3) the tool sensitivity.

Figure 3 presents some typical site survey data. The data are shown in terms of rms velocity, both as narrowband spectra (typically with a bandwidth of 0.375 Hz over the frequency range 0 to 100 Hz), which are diagnostically useful if one wishes to identify sources of vibration and, perhaps, resonance phenomena that may amplify vibration amplitudes, and as one-third-octave band spectra, for comparison with the Vibration Criterion (VC) curves.

FOUNDATION DESIGN

In our experience the amount of attenuation that can be achieved from site ambient vibration and from vibration generated by "in-house" sources, by special foundation design, is quite limited, in most instances. For example, we have found isolation breaks between different foundation systems to have insignificant effect in limiting vibration propagation. This is due to the fact that soil medium is the primary path for wave propagation.

Recently we have had occasion to study the performance of mixed foundations such as deep-drilled piers adjacent to mat foundations. Here computer models of ground/foundation interaction have shown some benefits in terms of attenuation.

Various foundation systems may be found to be beneficial for the unique soil conditions at a particular site. We usually provide specific recommendations based on our review of the geotechnical reports.

LAYOUT DESIGN

The layout of the facility is important insofar as the placement of major mechanical systems relative to the process floor is concerned.

It is recommend that the "energy center" lie at a horizontal distance no closer that 16m (if possible, further) from the nearest column supporting the sensitive area.

Horizontal separation should also be achieved between the fab and the exhaust fans and the make-up fans.

As far as possible the sub-fab should be kept clear of mechanical systems other than hook-up (tool) related systems. Process-support systems (process vacuum, house vacuum, UPW, PCW, oil-free air, etc.) should be separated horizontally (i.e. outside the fab footprint) from the fab building.

Emergency equipment that must be periodically exercised (such as an emergency generator) should be separated horizontally also.

STRUCTURAL DESIGN

The structural design of the floor that will support the vibration-sensitive equipment is of paramount

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importance in achieving a good quality of vibration performance.

As a multivariate regression analysis of the performance spectra for many operating process floors at start-up in the “as built” condition, we have found that the vibration can be predicted based on certain aspects of the structural design – stiffness and resonance frequency being two of these.

For Vertical Vibration: $V_V \propto 1/K_V$

For Horizontal Vibration: $V_H \propto 1/\sqrt{K_H}$

Where V_V and V_H are the one-third octave band velocities at the respective vertical and horizontal resonance frequencies. It is at these resonance frequencies that the maximum vibrations occur.

K_V is the vertical static stiffness in the middle of the column bay (this is a local, as opposed to a global, stiffness). K_H is the “global” horizontal stiffness of the fab floor. This stiffness encompasses the total stiffness of all the columns, shear walls and other structures that serve to resist movement of the floor under horizontal loads.

The fundamental vertical resonance frequencies of most current floors, with which we have been involved, lie in the range 20 to 65 Hz. Horizontal resonance (cantilever mode) frequencies are much lower; typically in the range 4 to 8 Hz.

MECHANICAL DESIGN/ISOLATION

No structural design will perform well with a poor mechanical design. Furthermore, it is not cost-effective to provide an excessively stout structural design with the intent that the mechanical design will be less relevant. The most cost-effective (and historically successful) method is to provide a balanced structural and mechanical design. With this in mind, our structural designs assume a specific quality in the mechanical design and installation.

The primary sources of vibration in the fab building, at start-up, are the mechanical systems that supply the building with conditioned air, compressed air, vacuum and general building services. Emergency systems may also have to be included within the equipment list since these systems (emergency generators, smoke exhaust fans, etc.) have to be “exercised” periodically.

It is important that all major items of equipment (with ratings in excess, say, of 3kW) be designed and installed in such a way that the vibration they transmit to the building structure is controlled. Vibration control must also encompass mechanical systems such as ductwork and pipework since these systems can also generate (via turbulent fluid flow) and transmit vibration. The latter requires both isolation systems and limiting of the fluid flow velocity.

Our recommendations for mechanical equipment vibration control are as follows:

Mechanical Vibration Control Specification

We provide a specification entitled Mechanical Vibration Control and Isolation, which incorporates a Vibration Isolation Schedule in which, all major mechanical systems will be listed and assigned vibration isolation details.

We require that we review purchase specifications for the individual mechanical systems such as AHUs, MUAs, EFs, etc. to ensure consistency with the above specification and to add appropriate noise requirements into these specifications.

Dynamic Balance of Equipment

Recommendations for the dynamic balance of rotating equipment are included in the specification. The balance standards given for “critical” fans are appropriate only to direct drive systems - with or without variable frequency drives (VFDs). In general we recommend against the use of belt-driven systems, especially for critical fans within 15 m, say, of the vibration-sensitive floors. The critical fans generally include all scrubbed, general, and other major exhaust fans, VOC system fans, and recirculation and make-up air handlers located within the fab and the fab support buildings.

Ductwork and Pipework

General recommendations for the isolation of ducting and piping systems - especially where these are connected to vibration-isolated equipment - are included in the specification. It is most important to limit fluid flow velocities in pipes and ducts since turbulence associated with fluid flow can form a substantial vibration source. For this reason we recommend that air flow velocities be limited to 9 m/s, and liquid flow velocities to 3 m/s.

We recommend also that major pipes and ducts (in excess, say, of 100 mm in diameter and 500 mm in diameter, respectively) located in the sub-fab be supported from the sub-fab floor and not directly from the waffle floor, even with vibration isolation hangers.

Inertia Bases

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We recommend that inertia bases, complying with the requirements given in the specification, be used on all liquid pumps and on the scrubbed exhaust fans. The structural design must take these loads into account.

Fan Units/Air Handlers

We require a high level of quality, in terms of operating efficiency, balance and vibration isolation, on the recirculation air fans, vertical laminar flow (VLF) fans, make-up air fans and air handlers that serve the cleanroom or which lie within 15 m (say) of the vibration-sensitive floor.

We generally prefer plug fans operating against a low static pressure, in which the operating tip speeds are low. Such fans are generally much less energetic as regards vibration, and quieter than other designs.

Vaneaxial fans however may be acceptable especially if care is taken to limit flow velocities in associates plenums and ductwork. Recently, fabrication facilities have been utilizing fan filter units (FFUs). Proper specification of these FFUs for both vibration and noise control should yield satisfactory performance of the process floor.

CONSTRUCTION DOCUMENTS & ADMINISTRATION

We work with the design team in the development of the construction documents. We usually carry out reviews of the construction document packages (presumably 50% and 95%) to verify their compliance with our recommendations.

During this phase, we usually provide a project-specific vibration isolation specification. We assist the design /contractor team in the development of specifications for major mechanical systems, vibration isolation hardware, etc. We review discipline-specific drawings and documents for their adequacy as regards vibration control. We always review final construction packages as they are issued.

We provide detailed input to construction documents (drawings and specifications) in the areas of structural, mechanical, process, and architectural design. We revise our calculations, as necessary, to reflect the final design included in the construction documents. We review all construction packages as they are issued

During the construction phase, we provide construction support on issues related to vibration control. We review relevant bid submittals and sometime assist in witnessing factory component tests. We evaluate field change requests as they relate to vibration issues. We make field inspections at an appropriate time during construction when most base building systems are installed. At that time we inspect the installation of vibration isolation systems and provide a punch list of items that may require corrective action by the contractor.

Figures 4 and 5 present some typical “inappropriate” isolation installations detected in a field inspection. In Figure 5, the spring isolation efficiency is reduced due to binding at the side restraints. In Figure 6, the isolation is not efficient because of the rigid through-bolting. These are but a few of the common isolation installation problems. We must emphasize on the importance of field inspections to capture sometimes subtle problems that can lead to poor vibration conditions. It is our experience on many projects that vibration and noise control hardware is often improperly installed, in spite of the good intentions of the contractor. Later corrective action can be difficult, if not impossible.

STRUCTURAL EVALUATION

At the completion of construction of the fab primary structural elements, we carry out a structural evaluation. We have found this type of evaluation to provide valuable information in confirming the actual performance of the facility. The goal of the structural evaluation is

1 - To confirm the predicted structural element (waffle, column, and foundation) stiffnesses by means of in-situ measurements.

2 – To ascertain the frequency response of various structural elements (or combinations of elements) by drive point mobility measurements. These data show the resonances and give indications of the damping characteristics of the element under test.

3 - To characterize the manner in which vibrations are propagated through the structure by transfer mobility and attenuation measurements. Specifically, we attempt to quantify how vibrations are transmitted or attenuated by the structure.

This structural evaluation allows us to compare the in-situ characteristics of the structure to the design theoretical calculations. In addition, the test data gives us additional useful data related to some of the unique structural design features employed in the fab design.

Figures 7 and 8 present the typical structural evaluation data. In Figure 7, the accelerance data collected during the structural evaluation is compared with the design data. In Figure 8, the predicted vibration propagation data are verified by the test data.

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The accelerance test data are used to verify that the process floor complies with the scanner accelerance criteria. The vibration propagation data can be used to support special tool/equipment installations.

FINAL EVALUATION

We carry out a full final vibration evaluation of the completed facilities in the as built condition (after building mechanical systems are operating but prior to tool hook-up and operation). The measurements are used to verify compliance of the "as built" fab building with the vibration criteria. As part of this task, we also carry out a full inspection of the as built mechanical isolation systems. We prepare a punch list of items that may require corrective action or modification by the contractor.

When we evaluate a facility floor, it is important to note that the floor performance is quantified on the basis of the "mean-plus-sigma" statistic of vibration data acquired at many measured locations randomly distributed over the floor area. This statistic is a useful measure of the utility of a process floor since, for a statistically "normal" distribution, it defines the condition at or below which 84 percent of the data lie. Performance cannot be meaningfully based on either the "noisiest" or the "quietist" location.

Statistical summaries of the ambient vibration data measured on 300mm fab process floors are shown in Figures 9 (Vertical), 10 (Horizontal: north-south), and 11 (Horizontal: east-west), in comparison with the appropriate criterion for each floor. The floor vibration criterion is met on this Fab process floor is met to the great care given in the vibration design. In the vertical direction, the vibration performance is influenced by tonal vibration at 55 Hz, which is due to building mechanical equipment. The field inspection recommends simple improvement to the mechanical equipment isolation that will reduce the impact.

In the horizontal directions, the low frequency structural floor resonances are visible between 5 and 15 Hz. However, performance in the horizontal directions is also primarily influenced by tonal vibration.
Experience shows that the tones just below 30 and 60 Hz tend to be associated with tool support equipment located in the subfab (dry pumps, small chillers, power conditioners, etc.).

Those at other frequencies tend to be associated with base build mechanical equipment (large liquid pumps, air handlers, exhaust fans, etc.). It is the latter that are most significant in this case. Again, the follow-up field inspection suggests that this situation may be improved by adjustments to the isolation hardware of certain mechanical equipment identified in the inspection.

SUMMARY & CONCLUSIONS

This paper presents an integrated vibration design process for a 300mm fab. This design process, which has been applied in the design of several 300mm fabs, includes design criteria, site survey, foundation design, layout design, structural design, mechanical design, construction documents and administration, structural evaluation, and "as built" evaluation.

This integrated approach is illustrated by the design and test data of some 300mm fabs.

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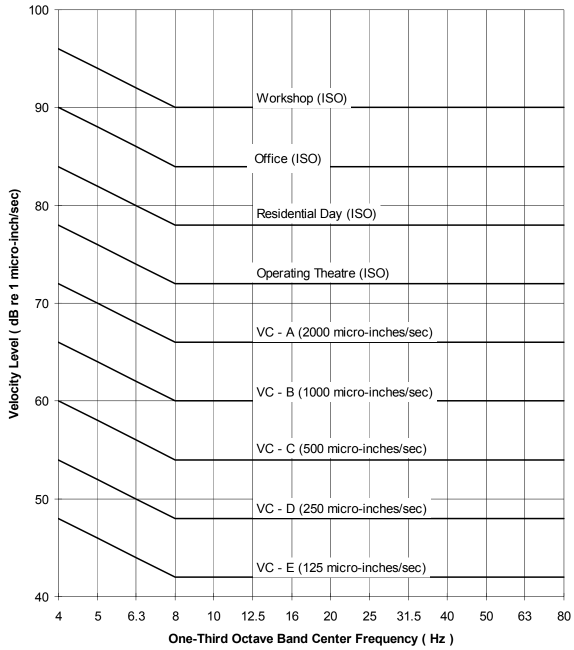


Figure 1: Generic Vibration Criterion (VC) Curves for Vibration-Sensitive Equipment

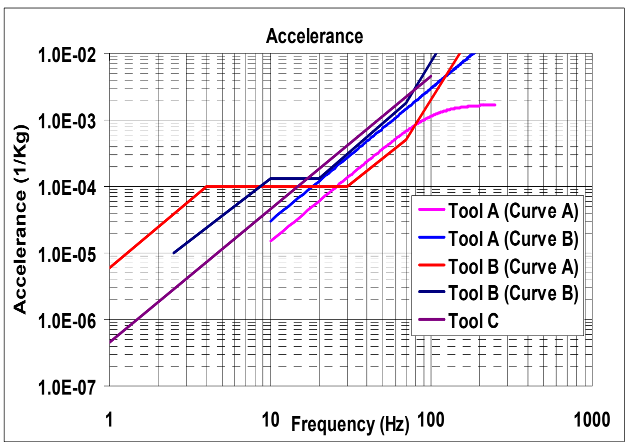
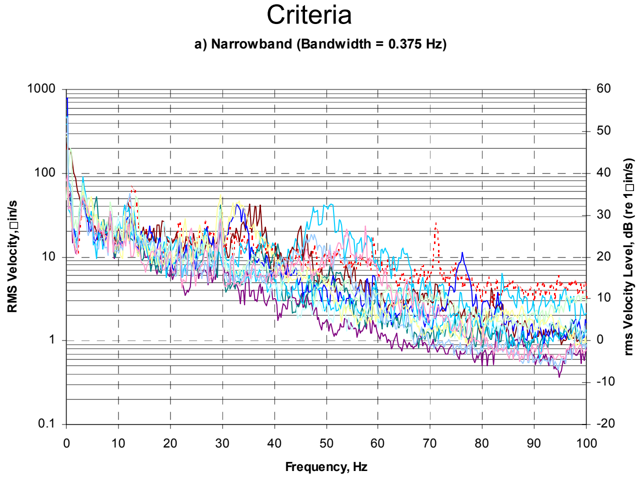


Figure 2: Scanner Acceleration Criteria



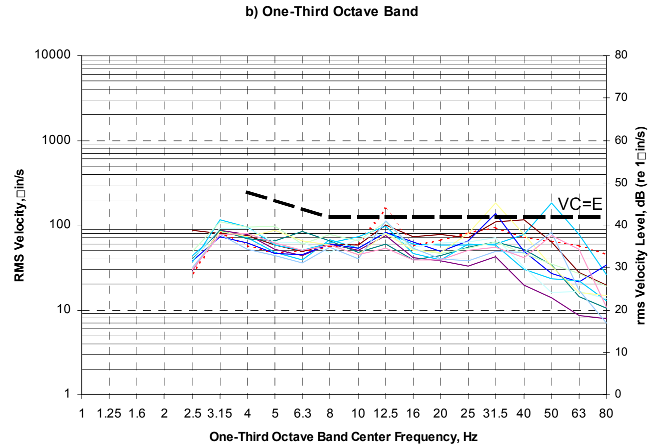


Figure 3: Illustration of a "Typical" Site Survey Data

Figure 4: Springs supporting mechanical equipment collapsing, and with isolation efficiency reduced due to binding at side-bar restraints

Figure 5: Mechanical equipment isolation (neoprene pad) efficiency reduced due to through-bolting

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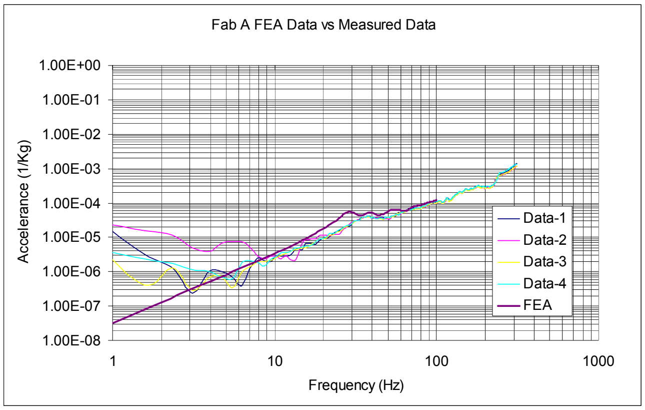


Figure 6: Structural Evaluation Data – Process Floor Acceleration Data

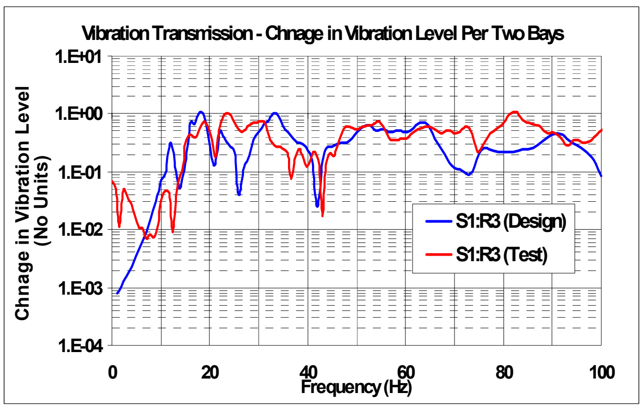
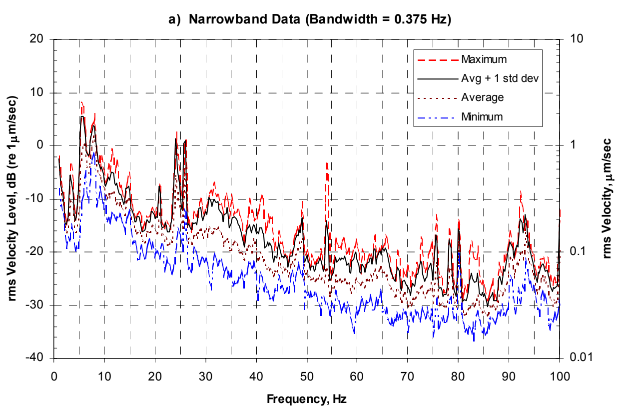


Figure 7: Structural Evaluation Data – Vibration Propagation



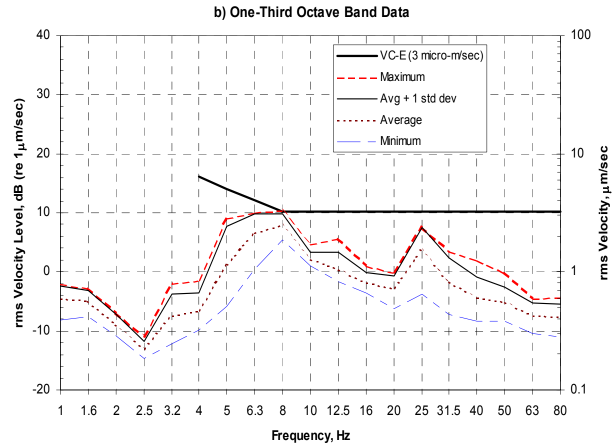
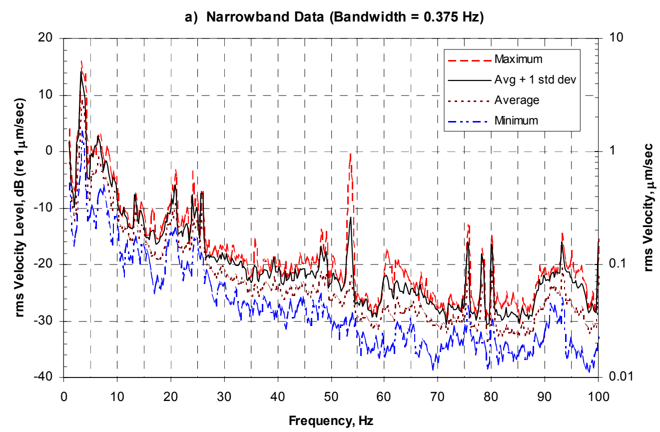


Figure 8: "As Built" Evaluation Data – Process Floor, Vertical



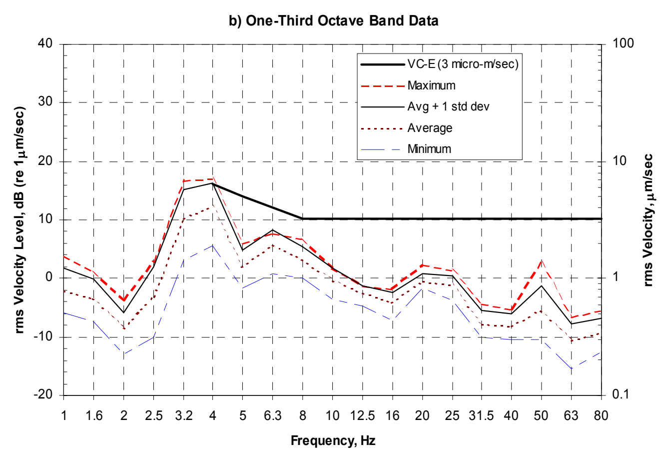


Figure 9: "As Built" Evaluation Data – Process Floor, Horizontal

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