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Generic Criteria for Vibration-Sensitive Equipment

Colin G. Gordon

Colin Gordon & Associates
San Mateo, California 94402

ABSTRACT

When designing facilities for research, microelectronics manufacturing and similar activities, it is generally necessary to have vibration criteria which are generic (i.e., applicable to classes of equipment and activity) rather than specific to particular items of equipment. This paper describes the derivation and use of one such set of criteria that is based on one-third octave band vibration velocity spectra. The paper also discusses the need to develop methods and standards for measuring the vibration sensitivity of equipment. Some examples are given which illustrate the considerable confusion in equipment sensitivity standards that exists at the present time. A plea is made to equipment manufacturers and users to develop and call for, respectively, specifications that are real and precise. This is especially important as the high-technology community enters the "age of the nanometer."

1. INTRODUCTION

In the late 1970s the San Francisco and Los Angeles offices of Bolt Beranek & Newman Inc. (BBN) became involved in vibration problems that were being experienced by Intel in their Livermore (California) and Aloha (Oregon) facilities. At about this time the Perkin-Elmer Series 100 Microalign (a projection aligner for lithography) was introduced.

It was clear in working with this machine that the primary vibration problems occurred at frequencies that coincided with resonances within the equipment. The major resonance involved the isolation mounts that lay between the body of the machine and the carriage. This resonance caused large out-of-phase motion between the microscope (used by the operator to make the alignment) and the carriage which held the wafer and mask assembly.

At the time of these early studies the Fast Fourier Transform (FFT) analyzer was not commonly available. Measurements were carried out using a one-third octave band "real-time" analyzer since this was readily available and provided enough resolution for diagnostic purposes.

Because of the confusion in the early specifications — some manufacturers set limits on displacement, others on acceleration — we decided to show most of our data in terms of rms velocity, being a single step of integration and differentiation removed from displacement and acceleration, respectively. It is also easier to plot velocity on the "triaxial" paper that is often used to display displacement, velocity and acceleration values on a single graph.

The confusion of equipment specifications that existed then — and still exists as we shall point out later — is illustrated in Figure 1. Here we show our interpretation, at that time, of the specifications for five different E-Beam systems (used for mask-making and, potentially, for direct-write lithography). These show a vast range of requirements for supposedly very similar equipment doing the same job with identical requirements in terms of line width and resolution.

It was clear from these and other specifications that facilities could not be reliably designed to suit equipment on an item-by-item basis. We needed to devise a measurement and certification methodology that would indicate the "quality" of a floor in terms of its suitability for broad classes of equipment. In other words, we needed to develop generic criteria.

It was with these, almost accidental, origins that the one-third octave band generic criterion curves — known sometimes as the BBN Criterion Curves[1] — were developed. These curves have been used extensively by the author and by others in the years since they were devised; and they have been extended (as the industry has moved towards finer and finer linewidths and resolutions) and refined during this time period. These curves, as they are currently proposed and used by Colin Gordon & Associates, are described and discussed in this paper.

The point must be made at this stage that other generic criteria — such as the FHA criteria — exist. These also have validity and utility insofar as they are based on adequate experience and that they are properly specified. The only purpose of this presentation is to describe and justify the origins and utility of the one-third octave band vibration criteria.

2. THE VIBRATION CRITERION CURVES

The criteria take the form of a set of one-third octave band velocity spectra labeled vibration criterion curves VC-A through VC-E. These are shown in Figure 2, together with the International Standards Organization (ISO) guidelines[2] for the effects of vibration on people in buildings. The criteria apply to floor vibration as measured in the vertical and two horizontal directions. The application of these criteria as they apply to people and vibration-sensitive equipment are described in Table 1.

The main elements of the criteria are as follows:

1) The floor vibration is expressed in terms of its root-mean-square (rms) velocity (as opposed to displacement or acceleration). It has been found in various studies that while different items of equipment (and people) may exhibit maximum sensitivity at different frequencies (corresponding to internal resonances), often these points of maximum sensitivity lie on a curve of constant velocity. It is important to note that there is little validity in a criterion that attempts to define a vibration displacement limit that is based on some small fraction of the dimension that is being examined (in the case of metrology) or inscribed (in the case of lithography). The resonant response of most systems is much too complex for this simplistic approach.

2) The use of a proportional bandwidth (the bandwidth of the one-third octave is twenty-three percent of the band center frequency) as opposed to a fixed bandwidth is justified on the

basis of a conservative view of the internal damping of typical equipment components. Experience shows that in most well-designed facilities the vibration is dominated by broadband (random) energy rather than pure tone (periodic) energy.

3) The fact that the criterion curves allow for greater vibration velocity for frequencies below 8 Hz reflects experience that this frequency range, in most instances, lies below the lowest resonance frequency. Relative motions between the components are, therefore, harder to excite and the sensitivity to vibration is reduced.

4) For a floor to comply with a particular equipment category, the measured one-third octave band velocity spectrum must lie below the appropriate criterion curve of Figure 2 at all frequencies.

These equipment criteria curves have been developed on the basis of data on individual items of equipment (in some cases tempered with judgment based on experience) and from data obtained from measurements made in facilities before and after vibration-related problems were solved. The curves are generic in the sense that they are intended to apply to broadly-defined classes of equipment and processes. They are intended to apply to the more sensitive equipment within each category that is defined.

The criteria assume that bench-mounted equipment will be supported on benches that are rigidly constructed and damped so that amplification due to resonances are limited to a small value. The criteria take into account the fact that certain types of equipment (such as SEMs) are supplied by the manufacturer with built-in vibration isolation.

It is important to note that these criteria are for guidance only. The "detail sizes" given in Table 1 appear to represent experience at the time of writing. They reflect the fact that the quality of design and of built-in isolation in most equipment tends to improve as dimensional requirements become more stringent. In some instances, the criteria may be overly conservative because of the high quality of built-in isolation that is provided. For example, many steppers currently used in photolithography are relatively insensitive to vibration.

3. Arguments in Support of the Vibration Criterion Curves

Over the years these vibration criterion curves have proved to be very useful. Some of the arguments in their support are discussed in this section.

3.1 The concept of velocity

Even at the earliest times of our work with the microelectronics industry it seemed that, because of the role played by system resonances, a displacement limit based (say) on some small fraction of the photolithography linewidth made little sense. Resonant systems are generally too complex for this type of simplistic approach. Also, in most systems, the overriding concern is with relative, not absolute, motion.

A reason why velocity rather than displacement appears to make the greater sense as a basis for a vibration criterion can be found in the concept of "jiggle" or "shake" as it applies to a camera. Blurring of a photographic image is not dependent upon the absolute distance that a camera is moved but upon the distance that it is moved *during* the period of exposure.

Thus, if the resolution of the photographic image is to be 100 microns and the exposure time is 0.01 sec, then an image of reasonable quality should be obtainable if the image movement caused by jiggle does not exceed 10 microns (ten percent of resolution) in 0.01 sec. This corresponds to a *velocity* of 1000 microns/sec. Many of the processes used in microelectronics, and in other fields of metrology, have, as their basis, processes that are photographic in nature (using photosensitive sensors or photoresists).

Even when the process is not photographic, similar arguments (for velocity rather than displacement as the measure of vibration) can be used. Consider, for example, the way in which the eye and brain register images. The series of images produced on a television screen by a slowly-panned video camera will be interrogated and accepted by a human observer without difficulty. It is only when the camera is jiggled or panned very rapidly that the human observer has problems. The eye/brain system, it would seem, requires the image displacement to be limited to some finite value during the "information assimilation" period. This suggests that velocity, rather than displacement, may be the governing criterion.

It would be a lie to pretend that in these early days (late 70s and early 80s) we developed these arguments to any useful extent. The concept, however, of using velocity as a primary measure of vibration received support from contemporary sources and, shortly thereafter, from other sources also:

ISO 2631/DAD 1 [2]

In 1981 the International Standards Organization (ISO) published a draft standard entitled "Guide to the Evaluation of Human Exposure to Vibration and Shock in Buildings (1 Hz to 80 Hz)." This document, based on the work of many researchers in the field, suggested that in the frequency range 8 to 80 Hz humans act as "velocity sensors." That is, the same velocity at different discrete frequencies will elicit the same response — be it the threshold of detectability or the threshold of discomfort. Below 8 Hz the body is apparently less sensitive to vibration — in the 4 to 8 Hz range the body acts as an acceleration sensor; in effect, higher velocities are needed to elicit the same response.

It is interesting to note that ISO 2631 recommends that, where many closely-spaced frequencies or broadband (random) energy are involved, one-third octave band filters should be used — to differentiate the effects of one frequency range from another. It is for this reason that the ISO guidelines can be included in Figure 2.

Perkin-Elmer Series Aligners

Around 1983 Perkin-Elmer published the vibration sensitivity curves for their Series 300 Microalign, a state-of-the-art projection aligner for photolithography. This was quite a remarkable achievement since prior to that time no manufacturers of such equipment had, to our knowledge, tested their equipment in detail for its sensitivity to vibration. The published curves, shown in Figure 3, were given both in terms of displacement versus frequency and acceleration versus frequency (both sets of curves are based on the same test data). Perkin-Elmer carried out the sensitivity tests using discrete (pure) tones of vibrational excitation.

The curves are noteworthy for at least three reasons:

1) The curves (for both vertical and horizontal excitation) are very jagged, showing sharp peaks and troughs at different frequencies. The troughs — the points of maximum sensitivity — correspond to internal resonances of the equipment. At these resonances large relative motions occur between equipment components. Similar resonant behavior had been observed in our earlier work on the P-E 100 Microalign.

2) The lowest resonance frequency occurs at about 11 Hz. Below this frequency (excitation frequencies as low as 1 Hz were used), the equipment is increasingly less sensitive.

3) The major resonances lie approximately on a line of constant velocity — approximately 125 microns/sec (5000 microinches/sec).

Yet another useful observation is that the P-E 300 is equally sensitive in the vertical and horizontal directions.

1000X Magnification Microscope

Around the year 1987 we had occasion to carry out detailed vibration sensitivity tests on a high magnification optical microscope. In the case of the P-E tests and much of the data compiled by ISO, the tests had been carried out using single pure tones. In the microscope tests we used, in separate tests, pure tones and one-third octave bands of random vibration. The latter were applied at the standard center frequencies (10 Hz, 12.5 Hz, 16 Hz, etc.). The results are shown in Figures 4 and 5.

Figure 4, with pure tone excitation, shows the jagged shape that demonstrates the importance of structural resonances within the microscope. The lowest significant resonance frequency lies close to 20 Hz; below this frequency the microscope is less sensitive to vibration. As before, the dominant resonances lie, approximately, on a line of constant velocity. In this case — for perceptible movement of a 1 micron test line — the appropriate base-movement criterion is 12.5 microns/sec (500 microinches/sec). Figure 4 suggests that the vertical sensitivity is less than the horizontal sensitivity, but not significantly so.

> Figure 5 is significant in that it demonstrates that peaks and troughs of response also occur when the excitation is presented in the form of one-third octave bands of broadband (random) energy. The system resonances are clearly excited but, perhaps, not to the same extent as they are when pure tones are used.

Not all equipment tests, of course, show such clear dependence upon vibration velocity. The evidence that we have in support of velocity is compelling, however. It seems to provide a useful index of measurement, in many instances, that can be used *without reference to frequency.*

3.2 The concept of bandwidth

Figure 6 shows typical vertical narrowband vibration spectra taken on three different cleanroom floors. Two of these are suspended floors — set on columns; one is of slab-on-grade design.

These spectra are presented to demonstrate the fact that most real-life vibration environments — and this is true everywhere, not only in the cleanroom — are dominated by broadband energy much more than by discrete (tonal) energy that is concentrated at one or several frequencies. Even in instances where discrete tones occur, these often occur in closely-spaced clusters.

Given this fact, in conjunction with the earlier observation that vibration-related problems primarily arise when equipment resonances are excited, we can ask the following question:

> Given these conditions (broadband excitation and resonance-controlled equipment performance), what is the appropriate bandwidth of measurement that should be used to evaluate the "quality" of a floor and its suitability for specific items of equipment in those cases where useful sensitivity specifications, based on pure tone excitation tests, are provided?

It can be shown that a resonator will respond with equal energy to a pure tone and to a band of broadband energy, when each is set to the same amplitude, if the broadband energy is applied with a bandwidth (the modal bandwidth) given by:

$$\Delta f = \frac{p}{2} h f_n \qquad (1)$$

where f_n is the resonance frequency and h is the loss factor (a measure of damping) of the resonator.

Equation (1) makes two important points:

(1) The higher the damping of the structure, the wider is the range of frequencies to which the resonator will respond and, therefore, the greater is the bandwidth of broadband energy that should be used in evaluating the adequacy of the floor. The concept of resonator bandwidth is illustrated by the classical frequency response curves of Figure 7 which show the effect of damping on the response bandwidth.

(2) Assuming constant damping, the measurement bandwidth should increase in direct proportion to the frequency — that is, the measurement should be carried out using proportional bands rather than narrowbands (with constant bandwidth).

The loss factor (h) of typical complex structures of the sort encountered in metrology and photolithography equipment might reasonably lie in the range 0.01 to 0.1. The appropriate proportional bandwidth for measurement should lie (from Equation 1) in the range:

$$\frac{\Delta f}{f} = 0.016 \text{ (or 1.6\%) to } 0.16 \text{ (or 16\%)}$$

The bandwidth of the one-third octave is 23% of the band-center frequency. This lies just above the upper limit of this range. The one-third octave therefore provides a fairly conservative measure of broadband energy insofar as its effect on a resonator (or series of resonators) is concerned.

As a final word of clarification for this concept: Consider a system whose response is dominated by resonances having an average loss factor of 0.1. The manufacturer's specification, developed from pure tone tests, defines an amplitude limit at each of the major resonance frequencies of 125 microns/sec (5000 microinches/sec = 74 dB re 1 microinch/sec) as shown in Figure 3. The concept expounded here states that the same 74 dB threshold will apply to broadband vibration if the broadband vibration is measured using a proportional band filter with a bandwidth equal to 16% of the resonance frequency.

A similar argument can be used when the excitation spectrum includes closely-spaced pure tones. Here, to an extent dependent upon the damping of the resonator, those components within a certain range of the exact resonance frequency will serve to excite the resonance. In this situation, although narrowband analysis may be used to identify individual sources of vibration (for diagnostic purposes associated, say, with a vibration control study), a broader, proportional bandwidth must be used to evaluate the overall effects of these tones on the resonator.

This analysis does not attempt to deal with the more complex issue of what happens when several of the resonances — identified from pure tone excitation tests — are simultaneously excited by broadband energy or by tones. This perhaps adds reinforcement to our claim that the measurement method that is used for evaluation purposes should be reasonably conservative. Use of the one-third octave, it is argued, appears to provide that conservatism.

4. A Review of Contemporary Equipment Specifications

We have recently had occasion to review the vibration specifications for twenty-three different items of equipment currently used in microelectronics research and production. This represents but a sampling of the more than one hundred specifications that we currently have on file.

The forms taken by these specifications are summarized in Table 2. With few exceptions, the shortcomings of these are evident:

1) ***Waveform.*** Five of the specifications provide no guidance as to whether the signal should be measured as an rms (root mean square) value or as peak-to-peak or zero-to-peak values. (The latter, of course, derive from the days of the oscilloscope. Most modern instruments measure rms.) Thirteen of the specifications call for peak-to-peak; two call for zero-to-peak. Only three specifications call for rms measurements.

2) ***Bandwidth.*** Where measurements are called for in the frequency domain (requiring frequency analysis of the signal) it is essential, when the spectrum is broadband in character or when it includes closely-spaced pure tone components, that the bandwidth of measurement is defined. Of the twenty-two specifications calling for (or implying) frequency analysis, bandwidth information is given for only two. For the rest a decision as regards bandwidth is left to the whim of the measurer.*

3) ***Direction.*** About half of the manufacturers are explicit in stating that their specification applies to both vertical and horizontal vibration. (One of these, who has clearly carried out detailed measurements, quotes different limits in each direction.) The remainder provide no guidance.

4) ***Domain.*** With one exception, all of the specifications call for (or imply) frequency spectra — that is, measurements in the frequency domain. The one exception is quite explicit that the signal be measured using a passband of 1 to 256 Hz and that the overall signal within this band comply with their defined peak-to-peak limit. This specification makes little sense since, as we have shown previously, the response of typical systems is strongly frequency-dependent.

5) ***Frequency Range.*** There is great variation in the frequency range that is to be included in the analysis. Three manufacturers provide a limit at a single frequency only (5 Hz). This frequency presumably coincides with the resonance frequency of their isolation system. The implication is that the vibration at 4.9 Hz or 5.1 Hz is not important; neither is it important at any other frequency. Three manufacturers set limits at three different single frequencies. Here again there is a problem in interpreting the requirements at other frequencies. One specification sets limits only in the 70 to 80 Hz range. Several manufacturers set limits at frequencies as low as 1 Hz. Some would imply that the limits apply at even lower frequencies. This makes little sense given our earlier arguments about the critical role played by equipment resonances.

   Some manufacturers are more explicit. One manufacturer, in particular, shows detailed (and complex) curves of allowable vibration as a function of frequency. These are clearly based on comprehensive measurements. This same manufacturer gives details as to how to interpret compliance with their specification using different bandwidths of measurement. The form of this clearly shows their recognition that most real environments are dominated by broadband energy.

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* Some manufacturers have established measurement procedures that they use themselves for qualifying a site. This information is rarely included in their published specifications however.

6) ***Units.*** Eighteen manufacturers express limits in terms of displacement: Four (one indirectly) use velocity and one uses acceleration.

7) ***Equivalent Velocity Levels.*** Under the heading "velocity levels" we show our interpretation of each of these specifications when expressed in terms of velocity — in dB re 1 microinch/sec. In those few instances where bandwidth information is provided, we have converted the values to a bandwidth of one-third octave — in line with normal practice. Velocity levels are given at four frequencies, 5 Hz, 10 Hz, 20 Hz and 50 Hz. The most intense vertical broadband on slab-on-grade floors occurs generally in the 7 to 15 Hz range. On suspended (column-supported) cleanroom floors, the maximum vertical response occurs generally in the vicinity of the fundamental vertical resonance — around 20 Hz for relatively soft long-span floors; around 40 Hz for stiffer shorter-span floors. The range of velocity levels represented by the data of Table 2 is great: 36 to 74 dB at 5 Hz, 42 to 78 dB at 10 Hz, 48 to 81 dB at 20 Hz, and 48 to 87 dB at 50 Hz. Admittedly, each of these items of equipment is different and their uses are different. The range, however, is impressive (30 to 40 dB, a factor of 30 to 100 in terms of allowable vibration amplitude), reminiscent of the data shown in Figure 1.

5. DISCUSSION AND RECOMMENDATIONS

In this paper we have presented the origins and current form of the one-third octave band vibration criterion curves. We have shown how the form taken by these can be justified both in terms of units (velocity) and the use of proportional bands (one-third octave) rather than narrow (constant) bands. These criterion curves are recommended as a means of evaluating the "quality" of a floor that will support vibration-sensitive equipment. They are also recommended as a basis for setting design goals for new facilities.

The one-third octave band methodology does not, in any way, displace the value of high-resolution narrowband spectrum analysis for diagnostic studies. Such analyses are essential to the process of identifying sources of vibration and of quantifying resonance phenomena. If the proportional bandwidth methodology is used, it should be in conjunction with narrowband analysis — if a comprehensive vibration study is required.

In this paper we have also highlighted the confusion that exists in the vibration specifications provided by manufacturers of process equipment. With few exceptions, the information provided is so incomplete as to be useless as a basis for facility design; hence the past and present needs for generic criteria that are based more on conservative experience than on quoted vibration sensitivity data.

In much of our current work with the microelectronics industry we are setting design goals in the range VC-D to VC-E (250 microinches/sec to 125 microinches/sec). These goals are thought to be appropriate[*] to production line widths in the range 0.7 microns, required in some current devices, to 0.3 microns or less, anticipated for future devices. Facilities must be designed with future device requirements in mind. These design goals are vastly changed from the situation ten years ago when

[*] Current goals are, in many instances, highly conservative for lithography tools (steppers) on which the quality of vibration isolation is generally excellent. The current goals are much less conservative for inspection equipment.

VC-B (1000 microinches/sec) was considered adequate for the 5- to 7-micron lithography prevalent at that time.

Our experience with recently-constructed facilities, in which the process floors are exceptionally stiff and great care is taken in the selection and isolation of mechanical systems, shows that further improvements in vibration performance (below Curve VC-E) may be impossible to achieve without great cost in terms of siting and design. It is clear that if progress in microelectronics technology is to be maintained, greater responsibility for vibration issues must be accepted by the manufacturers of the process tools. In particular:

1) Vibration must be considered even more carefully than it is currently, when designing the structures and isolation systems of new equipment.

2) Vibration specifications must be developed for new (and old) equipment that are based on physical tests. These must provide specific and comprehensive guidance as to how sites should be evaluated so that compliance can be checked and guaranteed, with a reasonable factor of safety. Guidance for the testing of process equipment is provided in Reference 3.

As a further step in this process we suggest that:

3) Buyers and users of process equipment be more specific in requesting that the vibration requirements of equipment be fully specified by the manufacturer.

Bearing in mind the cost of most process equipment, it is difficult to understand why their vibration sensitivity is so neglected.

REFERENCES

1. Gordon, "The Design of Low-Vibration Buildings for Microelectronics and Other Occupancies," *SPIE Proceedings of the First International Conference on Vibration Control in Optics and Metrology*, vol. 732, pp. 2–10, 1987.

2. International Standards Organization, "Guide to the Evaluation of Human Exposure to Vibration and Shock in Buildings (1 Hz to 80 Hz)," *Draft Proposal ISO 2631/DAD1*, 1981.

3. Institute of Environmental Sciences, "Measuring and Reporting Vibration in Microelectronics Facilities," *IES-RP-CC-024 (Final Draft)*, 1991.

Criterion Curve (see Figure 1)	Max Level (1) microinches/sec (dB)	Detail Size (2) microns	Description of Use
Workshop (ISO)	32000 (90)	N/A	Distinctly feelable vibration. Appropriate to workshops and nonsensitive areas.
Office (ISO)	16000 (84)	N/A	Feelable vibration. Appropriate to offices and nonsensitive areas.
Residential Day (ISO)	8000 (78)	75	Barely feelable vibration. Appropriate to sleep areas in most instances. Probably adequate for computer equipment, probe test equipment and low-power (to 50X) microscopes.
Op. Theatre (ISO)	4000 (72)	25	Vibration not feelable. Suitable for sensitive sleep areas. Suitable in most instances for microscopes to 100X and for other equipment of low sensitivity.
VC-A	2000 (66)	8	Adequate in most instances for optical microscopes to 400X, microbalances, optical balances, proximity and projection aligners, etc.
VC-B	1000 (60)	3	An appropriate standard for optical microscopes to 1000X, inspection and lithography equipment (including steppers) to 3 μ line widths.
VC-C	500 (54)	1	A good standard for most lithography and inspection equipment (including electron microscopes to 1 μ detail size.
VC-D	250 (48)	0.3	Suitable in most instances for the most demanding equipment including electron microscopes (TEMs and SEMs) and E-Beam systems, operating to the limits of their capability.
VC-E	125 (42)	0.1	A difficult criterion to achieve in most instances. Assumed to be adequate for the most demanding of sensitive systems including long path, laser-based, small target systems and other systems requiring extraordinary dynamic stability.

Notes:

(1) As measured in one-third octave bands of frequency over the frequency range 8 to 100 Hz. The dB scale is referred to 1 micro-inch/second.

(2) The detail size refers to the line width in the case of microelectronics fabrication, the particle (cell) size in the case of medical and pharmaceutical research, etc. The values given take into account the observation that the vibration requirements of many items of the equipment depend upon the detail size of the process.

The information given in this table is for guidance only. In most instances, it is recommended that the advice of someone knowledgeable about the applications and vibration requirements of the equipment and process be sought.

Class	Waveform	Bandwidth (Hz)	Direction	Domain	Freq. Range (Hz)	Units	Velocity Level (dB re 1 μ in/sec) 5 Hz	10 Hz	20 Hz	50 Hz	Comments
A	p-p	not given	not given	Freq.	5	Displ.	62	—	—	—	—
A	p-p	not given	All	Freq.	5,10,50	Displ.	59	68	—	91	—
A	p-p	not given	All	Freq.	5	Displ.	59	—	—	—	—
A	p-p	not given	All	Freq.	5	Displ.	62	—	—	—	—
A	p-p	not given	not given	Freq.	>5	Displ.	62	68	74	82	"sine wave"
A	p-p	not given	not given	Freq.	>5	Displ.	59	65	71	79	"sine wave"
A	p-p	not given	not given	Freq.	5,10,50	Displ.	53	65	—	85	—
A	not given	not given	not given	Freq.	1 to 20	Displ.	51	57	63	—	p-p assumed
B	not given	not given	All	Freq.	1.5 to 100	Displ.	61	67	73	81	p-p assumed
B	o-p	not given	not given	Freq.	<5,5–10,>10	Displ.	59	74	80	88	3 ranges defined
B	p-p	not given	not given	Freq.	<5,5–10,>10	Displ.	62	68	74	82	3 ranges defined
B	rms	1/3 OB	All	Freq.	8 to 100	Vel.	—	60	60	60	based on VC-B
C	o-p	not given	All	Freq.	1 to 250	Accel.	74	78	81	77	complex formula
D	p-p	1 to 256	All	Time	1 to 256	Displ.	36	42	48	56	assume single tone
D	p-p	not given	All	Freq.	1 to 100	Displ.	39	45	51	59	—
E	not given	not given	not given	Freq.	50 to 60	Displ.	—	—	—	105	rms assumed
E	p-p	not given	not given	Freq.	5,10,30	Displ.	53	59	—	—	—
F	not given	not given	All	Freq.	1 to 100	Vel.	48	48	48	48	rms assumed
F	not given	not given	All	Freq.	<50,>50	Vel./Accel.	48	48	48	48	rms assumed
F	rms	not given	not given	Freq.	1 to 100	Vel.	48	48	48	48	—
F	p-p	not given	not given	Freq.	>5	Displ.	67	73	79	87	"no vibration below 5 Hz"
F	p-p	not given	not given	Freq.	1 to 60	Displ.	47	53	59	67	—
F	rms	.234	All	Freq.	1 to 100	Displ.	54	54	58	47	full details given

Class:
A. SEM/TEM
B. E-Beam (Mask and Direct Write)
C. Steppers
D. Repair
E. Analysis
F. Metrology/Inspection

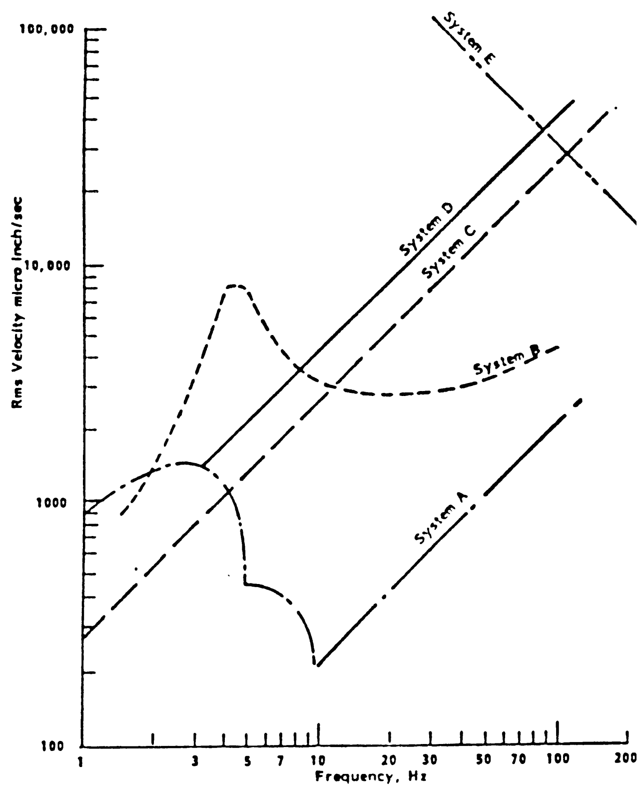


Figure 1: An interpretation of old (circa 1982) vibration specifications for E-Beam systems.

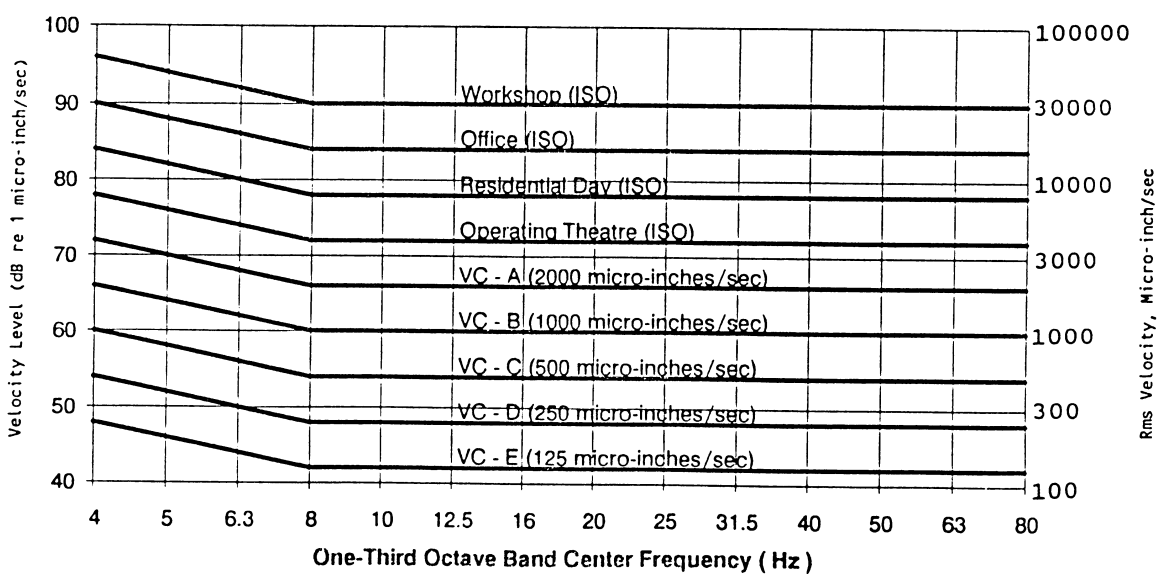


Figure 2: Generic vibration criterion (VC) curves for vibration sensitive equipment — showing also ISO Guidelines

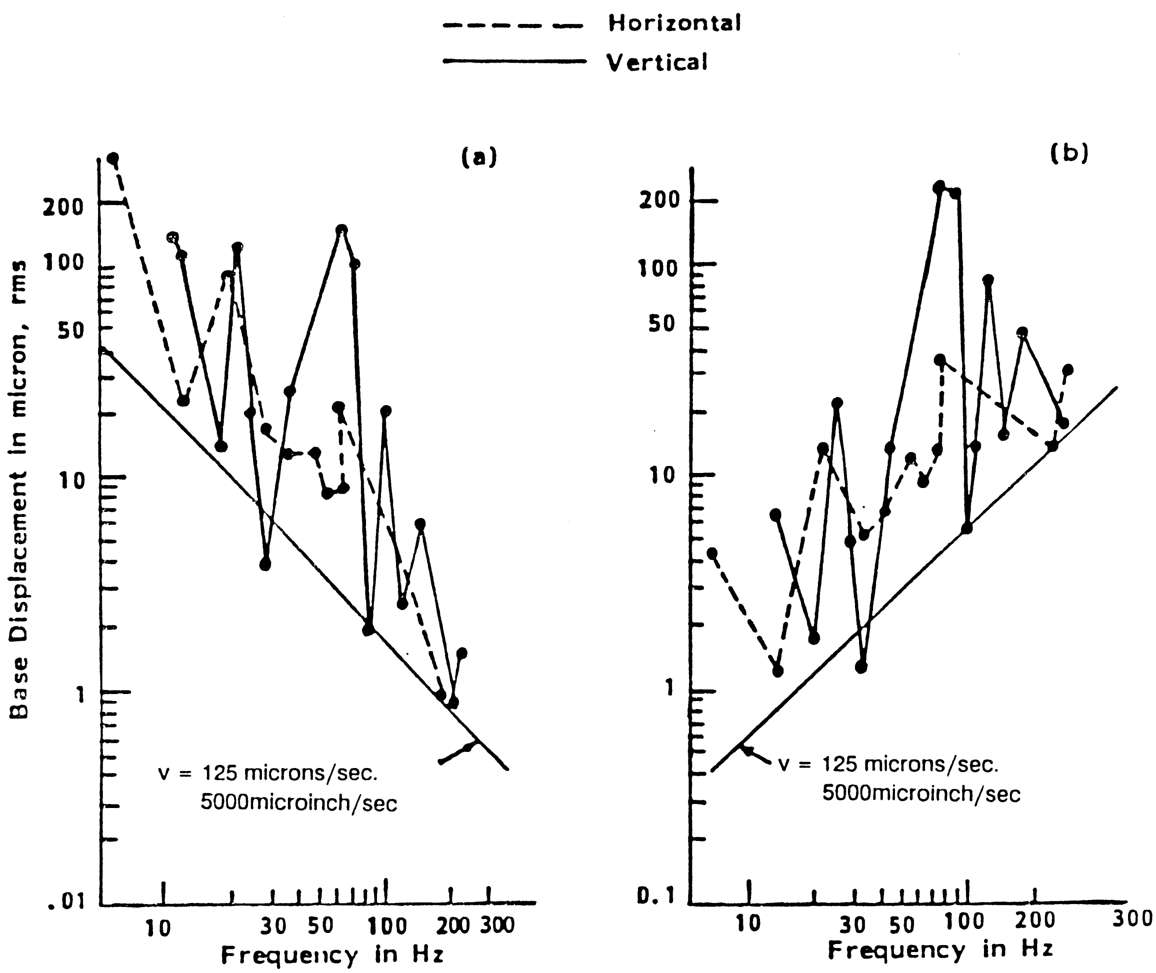


Figure 3: Pure tone vibration sensitivity curves for projection aligner for 0.1 micron motion in terms of

(a) Base displacement

(b) Base acceleration

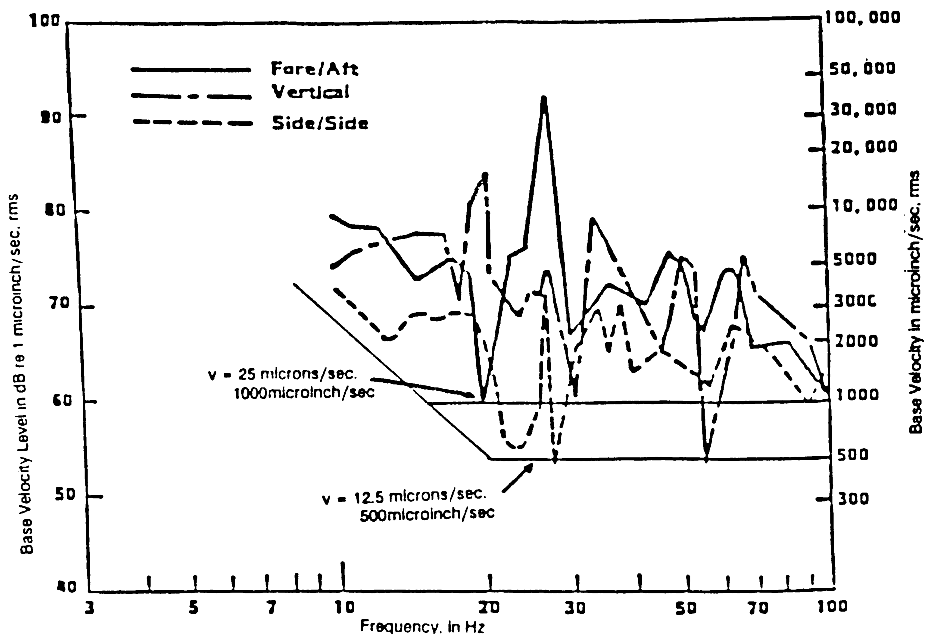


Figure 4: Pure tone vibration sensitivity curves for 1000x optical microscope for detectable motion of 1-micron test line.

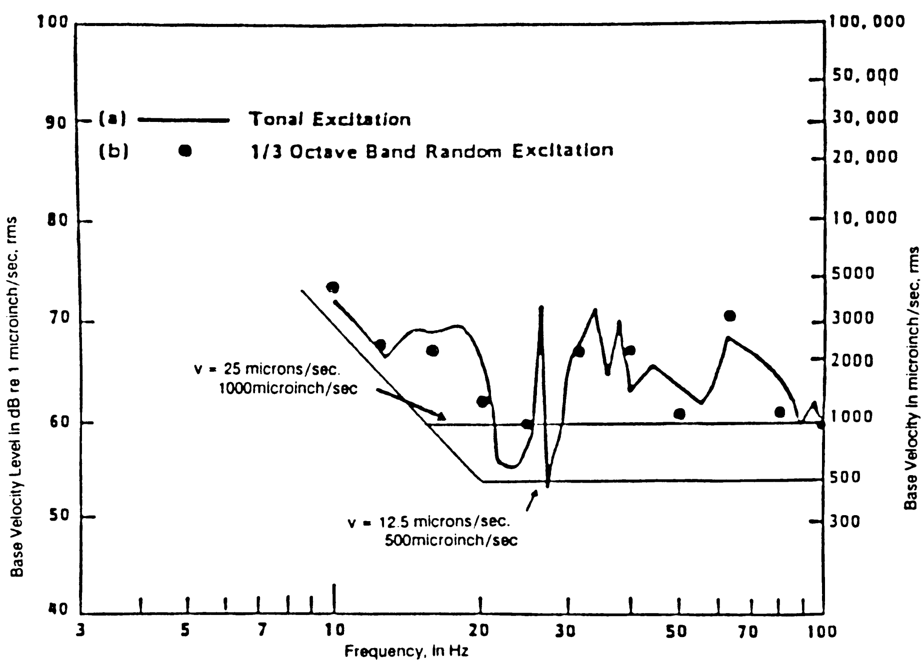
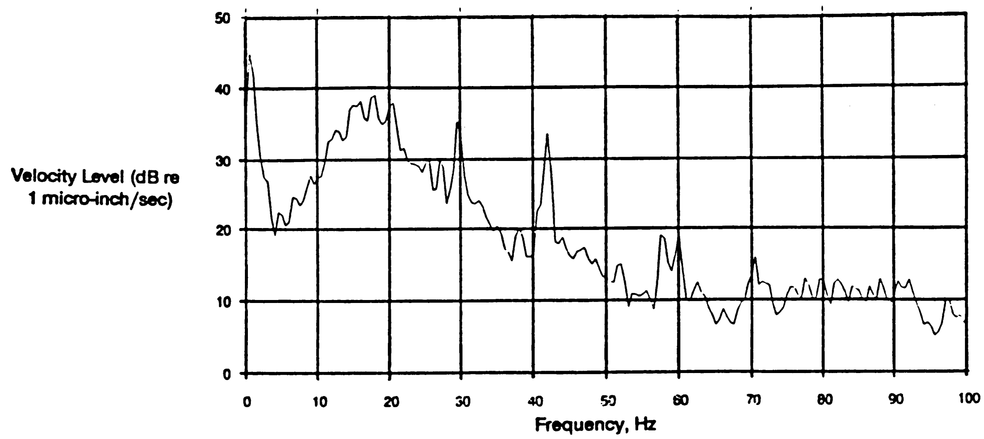
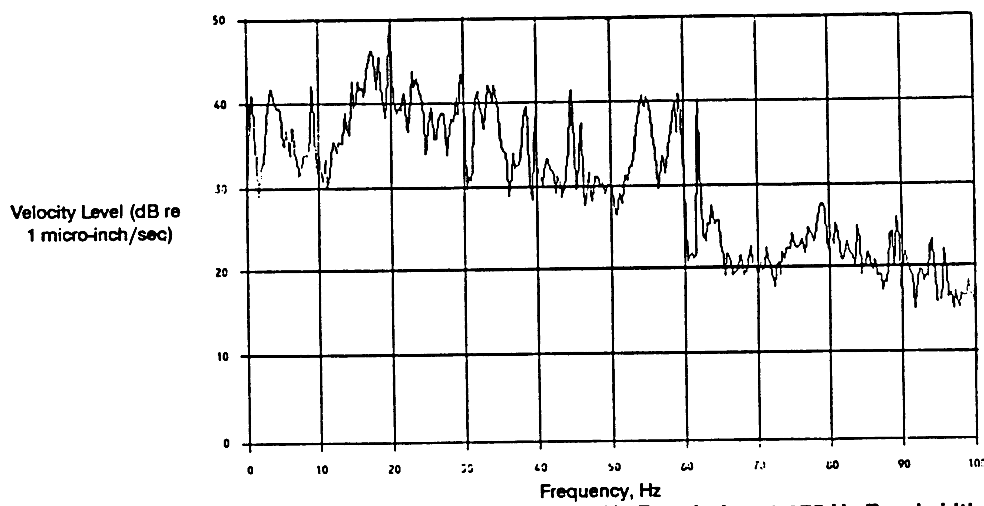


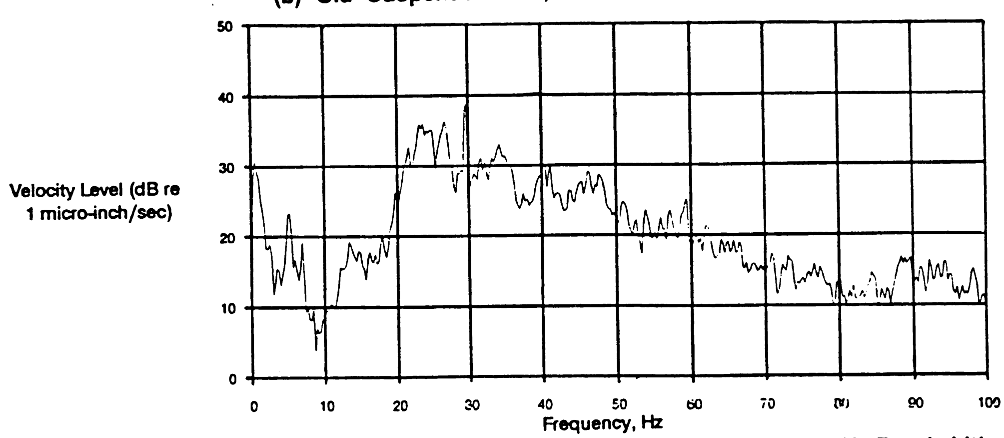
Figure 5: Comparison of horizontal (side-to-side) vibration sensitivity curves for 1000x optical microscope for:
(a) Pure tone excitation
(b) 1/3 octave band random excitation



(a) Slab-on-Grade, 0.5 Hz Resolution, 0.75 Hz Bandwidth



(b) "Old" Suspended Slab, 0.25 Hz Resolution, 0.375 Hz Bandwidth



(c) "New" Suspended Slab, 0.25 Hz Resolution, 0.375 Hz Bandwidth

Figure 6: Narrow band vertical vibration spectra on three typical clean room floors

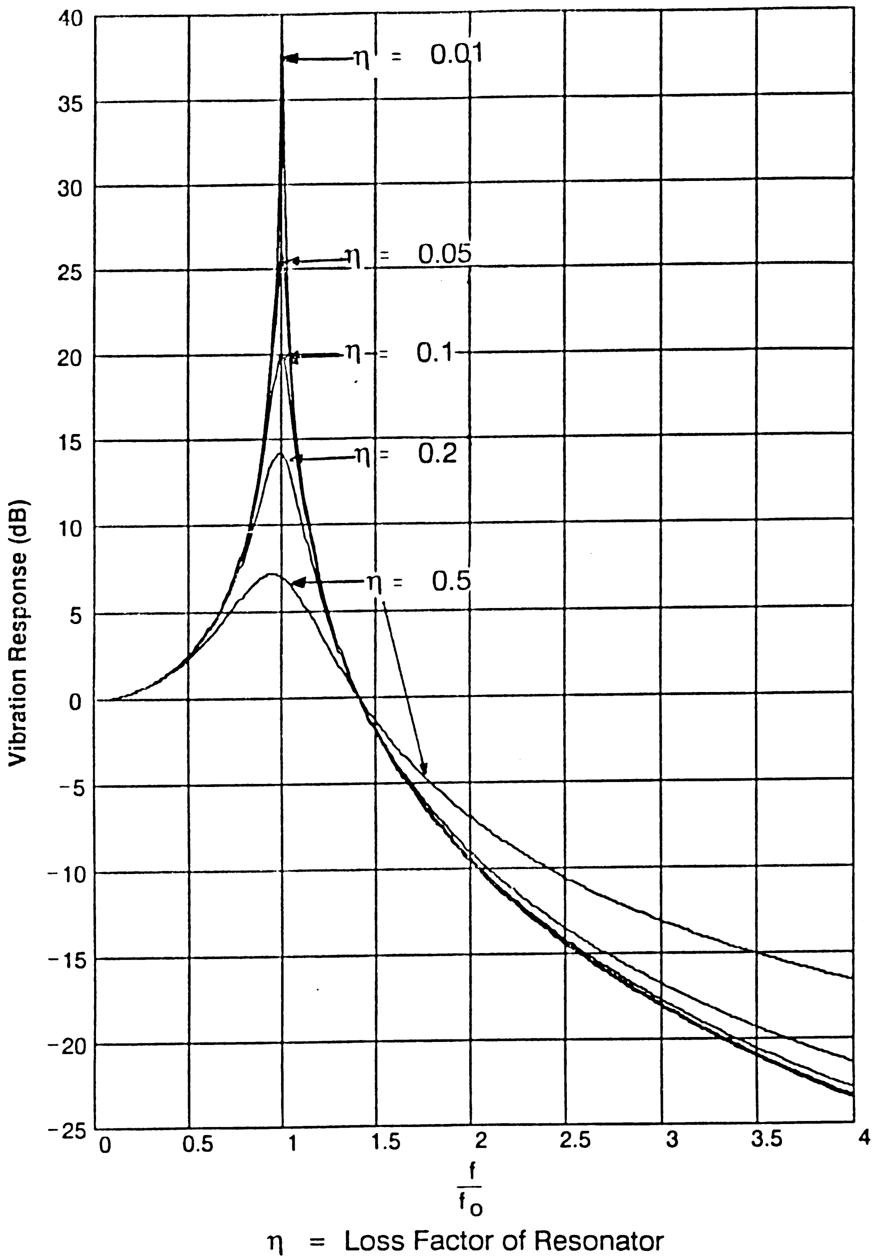


Figure 7: Response diagram for a simple (single degree of freedom) resonator with different amounts of damping