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Methods of Developing Vibration and Acoustic Noise Specifications for Microelectronics Process Tools

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ABSTRACT

The performance of optical tools used by the microelectronics industry is sensitive to their vibration and noise environments. Such environments result in internal tool vibrations that degrade tool performance. Relative vibrations between a tool and the workpiece on the order of only a few microinches per second can prevent the tool from successfully performing its task. Despite this, vendors often provide no specifications for allowable noise and vibration environments for their tools. In other cases, vendors provide allowable specifications that are incomplete, difficult to use, and/or hard to interpret for design-evaluation purposes. As a result, microelectronics facilities usually have to be designed very conservatively (and thus expensively) to assure acceptable tool performance. In this paper, we recommend simple test procedures that both vendors and users can implement to obtain useful specifications for allowable environments.

Keywords: vibration, specifications, noise, criteria

1. INTRODUCTION

At the SPIE conference "Vibration Control in Microelectronics, Optics and Metrology" in November 1991, we presented a paper[1] in which we bemoaned the fact that the vibration requirements for most process tools used by the microelectronics industry at that time were very poorly defined. Table 1 taken from that paper illustrates the confusion in the specifications offered by different tool manufacturers.

Two and one half years later the situation is hardly changed. Yet in that same period the requirements of the microelectronics industry in terms of line width and resolutions have continued to increase. Facilities are currently under construction in which it is planned that product with line widths in the range 0.15 to 0.25 micron will be produced, even though the tools capable of fabricating and testing such product may not yet be in existence.

In this environment there is clearly an increasing need for tool manufacturers to expend the effort not only to improve the vibration design of their tools -and this is being done quite successfully in many cases—but also to develop complete and accurate vibration specifications.

Our aim in this paper is to discuss ways in which tool manufacturers can carry out vibration tests in their own facilities without the expenditure of large amounts of effort or cost. In this paper we shall also discuss ways of developing acoustic noise specifications for tools, since noise sensitivity of certain types of tools is of growing importance.

2. VIBRATION AND NOISE SENSITIVITY

Many of the tools used in microelectronics fabrication and research are sensitive to vibration and acoustic noise. This is particularly so in the cases of tools used for photolithography, metrology and test. Vibration sensitivity has been identified as an issue for many years. It is only recently that noise has become a significant issue. This may be related, at least partially, to the growth in the diameter of wafers used by the microelectronics industry. This growth has been accompanied by growth in the size of the tools. This increases their susceptibility to excitation by airborne sound.

The maximum sensitivity of tools to vibration and noise disturbance occurs, typically, when components within the tool are excited at their resonance frequencies. At these resonances large relative movements can occur between components. It is these movements that cause operational problems such as image blurring, etc.

Experience shows that the lowest order resonances, those in the frequency range 10 to 50 Hz typically, are excited by the vibrations on the floor on which the tool is supported. These same resonances are not readily excited by acoustic noise, probably because of the poor coupling[*] at these frequencies between the sound field and the tool. In the few measurements that have been made of noise sensitivity, maximum sensitivity has occurred in the frequency range 100 to 300 Hz. In this range the potential for efficient coupling between the sound field and the typical tool is much improved. There is little doubt that even at these higher frequencies, resonances on, or within, the tool are the cause of relative movements and of operational problems.

3. VIBRATION AND NOISE ENVIRONMENTS

The vibration environment on the structural floor of a well-designed operating microelectronics cleanroom is, typically, dominated by broadband "random" energy, as opposed to pure tone "ordered" energy. Similarly the noise environment in the operating cleanroom will be broadband, as opposed to tonal, in character.

Although the same tool resonances will be excited whether the source of excitation is tonal or broadband, the degree to which they are excited will be different. It is important, therefore, that the testing method that is used to determine the vibration and noise sensitivity of a tool include excitation by bands of broadband energy as well as by pure tones.

4. VIBRATION AND NOISE CRITERIA

The one-third octave band vibration criterion curves that are widely used as a basis for site and facility evaluations and as a goal for new facility designs are described in Table 2 and Figure 1. The origin of these curves is discussed in Reference 1.

The vibration criteria are expressed in terms of root mean square (rms) vibration velocity as measured in one-third octave bands[**] of frequency over the band center frequency range 4 Hz to 100 Hz. We recommend that vibration specifications be based on tests in which both pure tones and one-third octave bands of vibrational energy be applied to the test tool. With these two sets of vibration sensitivity data the vibration requirements of the tool will be adequately described.

It must be noted that the vibration criteria of Table 2 and Figure 1 are intended to apply to vertical vibration and to horizontal vibration in each of the two orthogonal directions. In the case of a tool the latter axes would generally be described as "side-to-side" and "front-to-rear".

Current practice is to design the recirculation air systems of cleanrooms so that the noise levels in the cleanroom aisles lie at or below noise criterion curve NC-55 or 60. The noise criterion curves[2] are illustrated in Figure 2. The choice of criterion is a compromise between what is desirable and what is practically possible. Cleanrooms by their nature are very noisy, not only because of the large quantities of recirculation air that are involved but also because of the noise of the tools and other equipment that occupies the cleanroom.

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[*] The acoustic wavelengths in the frequency range 10 to 50 Hz lie in the range 100 to 20 ft., much greater than the typical tool dimension. Under this condition the efficiency of coupling between the sound field and the tool structure is very poor.

[**] The bandwidth of a one-third octave is twenty three percent of the band center frequency.

It should be noted that the noise criterion curves are based on a measurement bandwidth of one octave*** and that the curves extend over the band center frequency range 63 Hz through 8000 Hz. We recommend that noise sensitivity testing utilize pure tones and one-third octave bands of noise and that the frequency range of testing encompass frequencies from 50 Hz to 500 Hz or even higher.

5. DETERMINING THE PROBLEM THRESHOLD

In developing a tool specification it is necessary to select the criterion that will be used to determine the onset of vibration- or noise-generated problems. This is something that must be decided by the tool manufacturer. In some cases the judgment of problem onset may be made visually by the tool operator looking at a test slide (in the case of an optical microscope) or at the image of a test circuit in the case of a scanning electron microscope, set at some representative magnification. In other cases the test may involve monitoring the video signal from a beam-based tool.

Clearly the criterion that is selected must be adequate to truly and fairly define the problem threshold. It must also be as simple as possible so that the process of determining the sensitivity threshold of the tool for different stimuli (vibration and acoustic) and different frequencies, can be completed within a reasonable period of time.

6. VIBRATION TESTING

Although there are independent testing laboratories with vibration testing facilities, it is likely that these would not be well suited to conduct tests of the sort described in this paper. One reason is that most, if not all, of the large vibration tables operated by these laboratories are hydraulically powered. These tables are unlikely to be able to operate at the very low levels of vibration or with the resolution necessary to define the sensitivity curve for a typical microelectronics tool. Instead we recommend a test arrangement that can be put together quite quickly and inexpensively, and that would allow fairly accurate determination of the vibration sensitivity curve. The arrangement is illustrated in Figure 3.

It consists of a spring-supported base which in combination with a "long stroke" shaker forms a vibration table. The table is sized to carry the tool, the shaker and, if necessary a "counter weight" to adjust the position of the center of gravity so that, horizontally, it aligns roughly with the location of the shaker. The table must be large enough to carry the shaker with its axis set vertically and horizontally, so that the necessary vertical and horizontal sensitivity curves can be developed.

Suggestions for the various components are as follows:

(1) The base and springs can be formed from standard off-the-shelf hardware available from several manufacturers of vibration isolation systems. The base would be a concrete-filled inertia base of the sort commonly used to support industrial pumps. The springs should be selected for a static deflection, under the total supported weight, of about 4 inches. With this selection the vertical resonance frequency of the system will be about 1.6 Hz. The horizontal translational frequency will be slightly higher. Over the 4 to 100 Hz range of the vibration tests the response of the table to the shaker input force will be entirely "mass" controlled.

(2) The shaker should be a long stroke electromagnetic force generator capable of linear operation over the frequency range 3 to 100 Hz or thereabouts. The shaker should be driven by a low-noise amplifier and function generator capable of generating sinusoids and band-limited random noise. It is most important that the system be able to operate with minimal distortion so that the effects of different frequencies can be examined in isolation.

(3) The counter weight can be formed of blocks of steel or lead.

(4) The vibration sensor, used to measure the vibration environment to which the tool is exposed, should be placed on the table directly beneath the center of the tool. The sensor (probably an accelerometer) and its associated electronics must be capable of measuring the frequency spectrum of very low level vibrations at levels far below those shown in Figure 1.

The procedure to be followed in developing vibration sensitivity curves is as follows:

*** The bandwidth of a full octave is seventy one percent of the band center frequency.

At each frequency, in turn, over the study range the vibration to which the tool is exposed shall be increased until the point at which the sensitivity threshold is reached or until the output limit of the shaker is reached.

In the case of one-third octave band excitation, the bands should correspond with the standard bands shown in Figure 1.

When the excitation consists of discrete pure tones it will be necessary to identify the frequencies of maximum sensitivity and to plot out the details of the sensitivity curve, concentrating particularly on these frequencies.

Examples of sensitivity curves for both pure tone and one-third octave band excitation are given in Figure 4.

7. ACOUSTIC TESTING

The noise environment in the typical microelectronics cleanroom bas octave band levels approaching NC-55 to -60 as shown in Figure 2. The sound field is diffuse, in that the energy comes from all directions, and is spatially uniform. Furthermore it is almost always dominated entirely by broadband as opposed to tonal energy.

Past measurements have shown that significant leve ls of cleanroom noise can occur at frequencies as low as 8 Hz. For reasons explained earlier most tools don't exhibit significant response to noise at these low frequencies. It will be adequate, in most cases, to limit acoustic tests to the frequency range 50 Hz to 500 Hz.

The ideal environment for acoustic testing would be a space that would be classified as acoustically reverberant, having bard non-absorptive walls floor and ceiling. In such a space a single loudspeaker placed in a corner of the room, f acing into the corner, would be adequate to immerse the tool in a diffuse uniform sound field.

More practically it is likely that the tool will be located in a laboratory or assembly area sharing space, perhaps, with other tools. Here it may be necessary to surround the test tool with several loudspeakers to approximate the cleanroom environment. If the tool bas a bard wall several feet to one side of it, reflections from this wall can serve to irradiate the wall side of the tool.

A typical arrangement for acoustic tests is shown in Figure 5. Recommendations for the components are as follows:

(1) The loudspeakers and associated amplifiers and signal generators must be of high quality so that distortion is minimized. It is important that the effects of different frequencies can be examined in isolation.

(2) Acoustic tests should be carried out using one-third octave or full octave bands of band-limited noise.

(3) The noise levels to which the tool is exposed should be measured using a Class 1 sound level meter fitted with an octave band or one-third octave band analyzer. Measurements should be carried out over a hypothetical surface spaced some 3 ft. or so from the tool surfaces. The average level would, most probably, be used in defining the specification.

The procedure to be followed in developing the noise sensitivity curves is identical to that described earlier for the vibration sensitivity curves.

An example of a sensitivity curve for a tool exposed to octave bands of noise is given in Figure 6.

8. CONCLUSIONS

In this paper we have discussed the basic requirements for testing methods that can be used for developing vibration and noise sensitivity curves for tools used in microelectronics fabrication and research. Such curves would form the basis for siting specifications for these tools.

Clearly the test methods described here are not perfect. It will be necessary to customize the test hardware and techniques to the particular tool and the environment in which it is tested. In the case of vibration testing, difficulty may be found in setting the system up so that the three axes of translational vibration can be separated and isolated from more complex motions such as rocking and rotational movements. Difficulties may also be encountered in def1ning the criteria by which tool malfunction can be adequately defined.

In spite of these difficulties we are convinced that much is to be learned and gained by following procedures of the sort described in this paper.

9. REFERENCES

1. C.G. Gordon "Generic Criteria for Vibration-Sensitive Equipment". SPIE Proceedings Volume 1610, pp 71 to 85, Nov. 1991.

2. ASHRAE Handbook, Fundamentals, Chapter 7, "Sound and Vibration", American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA. 30329, 1993.

Table 1. A summary of the vibration requirements provided by manufacturers for an assortment of typical equipment.

Class	Waveform	Bandwidth (Hz)	Direction	Domain	Freq. Range (Hz)	Units	Velocity Level (dB re 1 *m* in/sec)				Comments
							5 Hz	10 Hz	20 Hz	50 Hz	
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

Table 2: Application and interpretation of the generic vibration criterion (VC) curves (as shown in Figure 1)

Criterion Curve (see Figure 1)	Max Level (1) micro-in/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 20X) 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 micron line widths.
VC-C	500 (54)	1	A good standard for most lithography and inspection equipment to 1 micron 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

Notes:

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

(2) The detail size refers to the line widths for microelectronics fabrication, the particle (cell) size for medical and pharmaceutical research, etc. The values given take into account the observation that the vibration requirements of many items 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 applications and vibration requirements of the equipment and process be sought.

Figure 1: Generic vibration criterion (VC) curves for vibration-sensitive equipment; showing also the ISO guidelines for people in buildings. (See Table 2 for description of equipment and uses.)

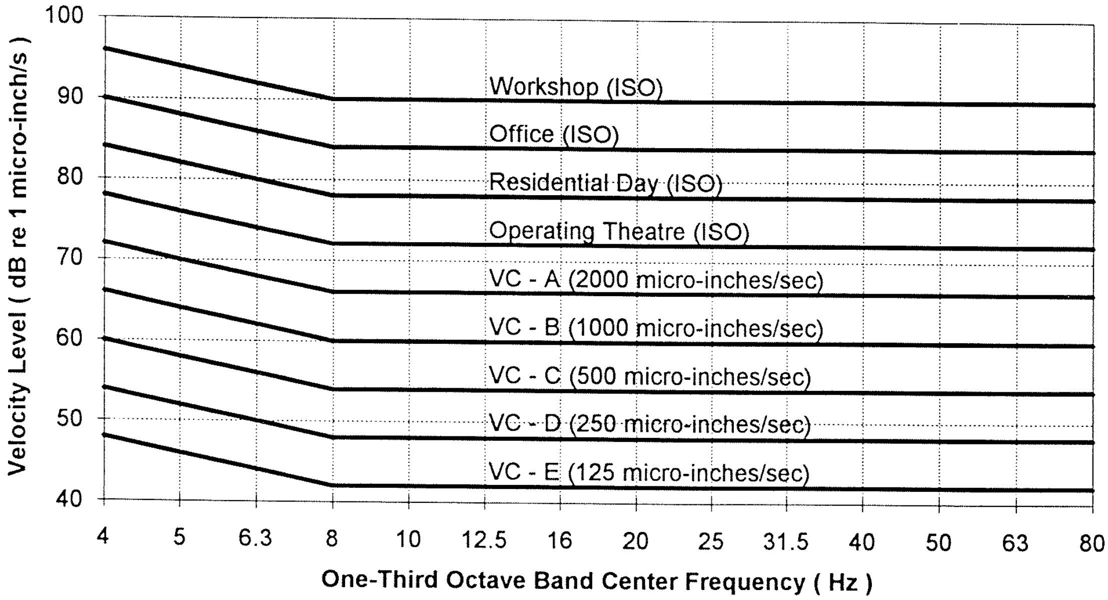


Figure 2: Noise criterion (NC) curves

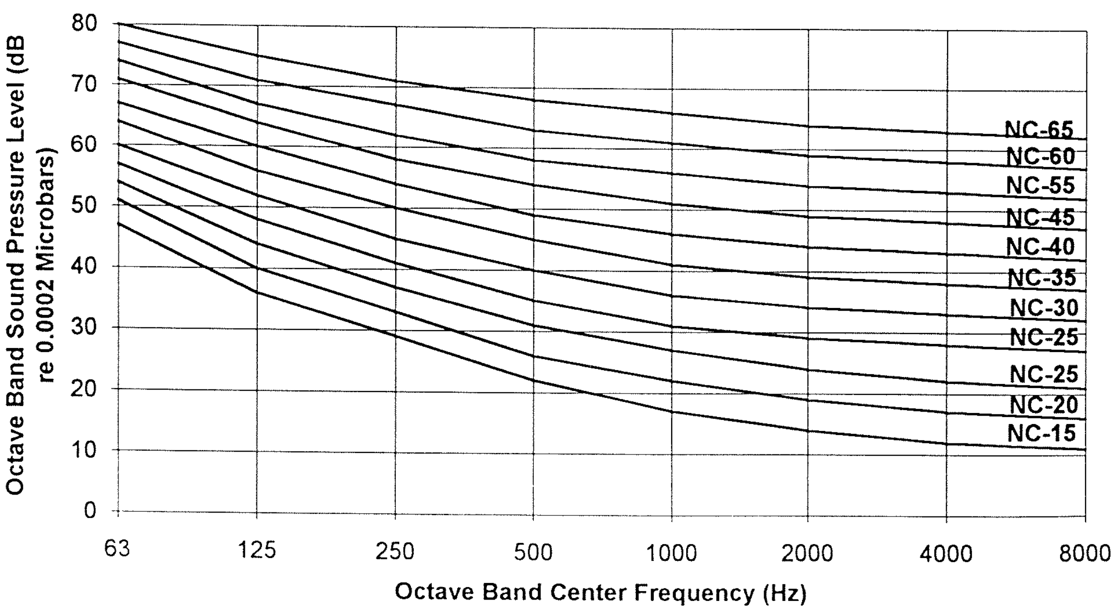


Figure 3: Vibration test arrangement

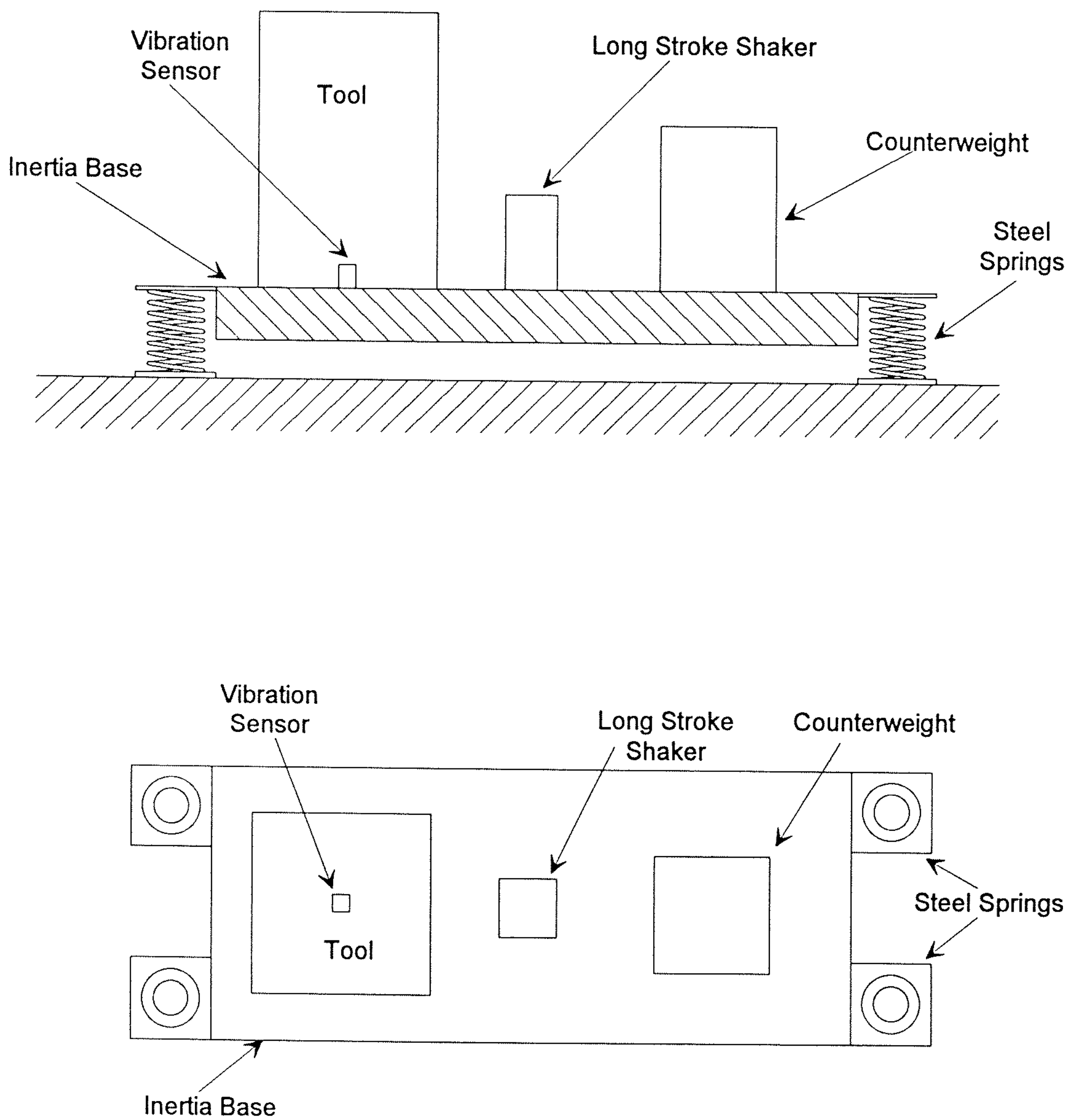
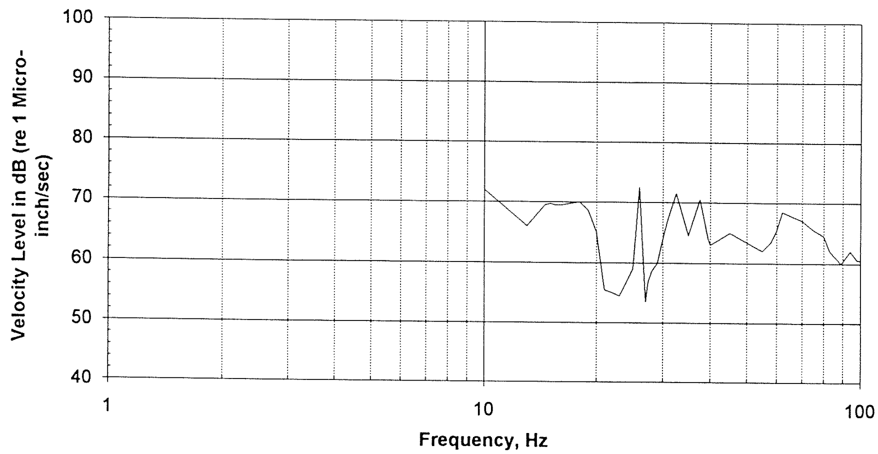


Figure 4: Example of vertical vibration sensitivity threshold curves for microscope

a) Pure Tone Excitation



b) One-Third Octave Band Excitation

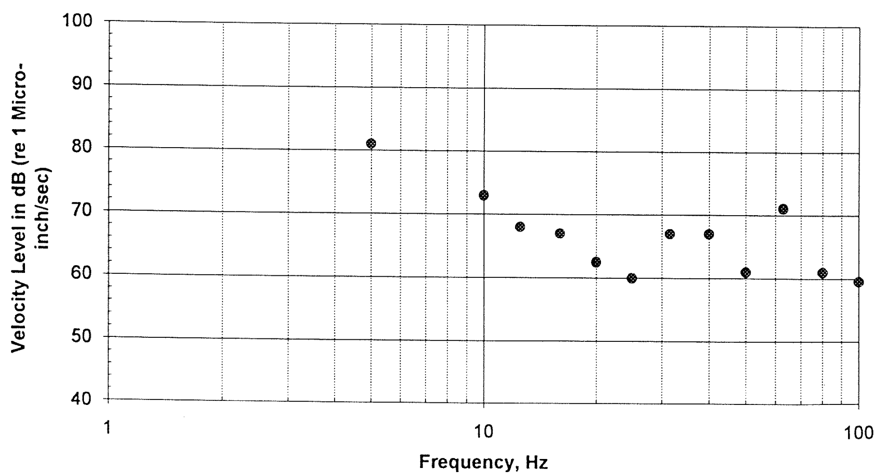


Figure 5: Acoustic test arrangement

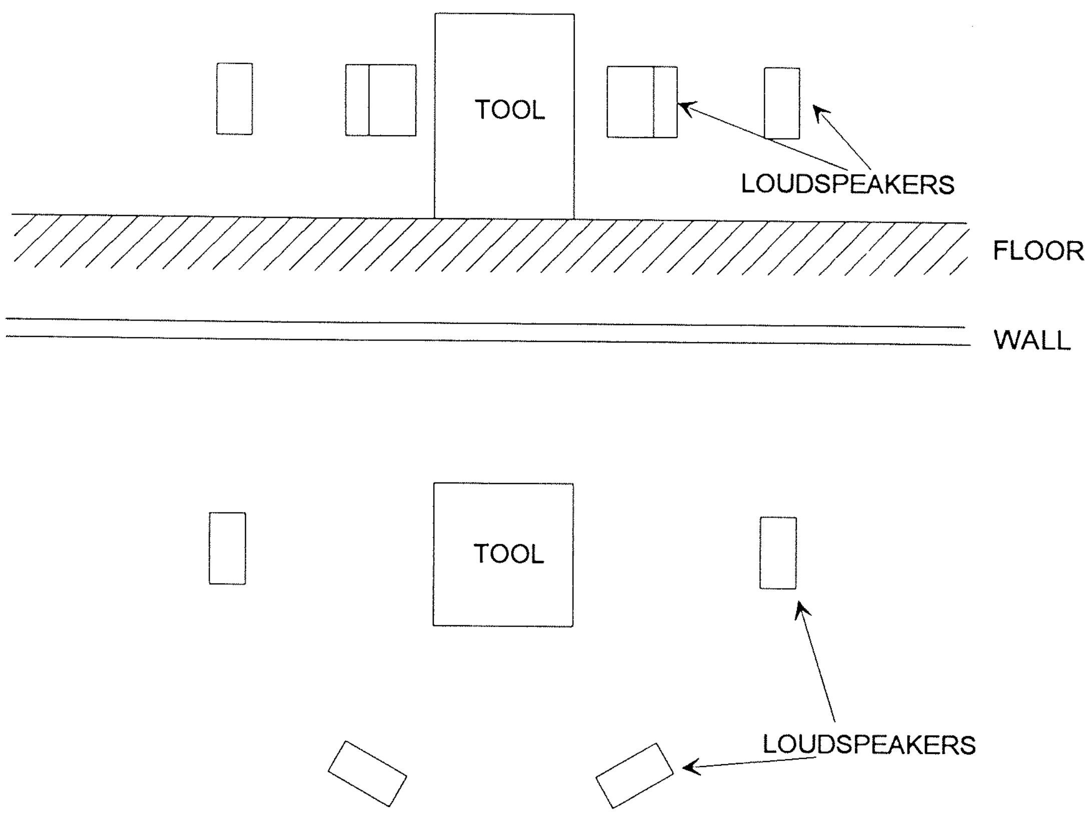


Figure 6: Example of octave band noise sensitivity threshold curve for process tool