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VIBRATION AND LABORATORY DESIGN

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1 INTRODUCTION

Scientific research is demanding ever increasing levels of accuracy of instrumentation. This is resulting in concern over the sensitivity of the instrumentation to environmental factors such as vibration. It is contrasted in the pressures to build laboratory building which are more flexible in use and more economical in cost.

Vibration sources include:

External Vibration Sources	Internal Vibration Sources
road traffic rail traffic	building services plant vibrating laboratory equipment footfalls door slams

TABLE 1: Vibration sources

Vibration from the various sources is transmitted via the building elements and the instrument mountings to the instruments themselves. The instrument mounting could be a specialised mounting arrangement, a vibration isolated table or a simple laboratory bench. These paths are summarised in Figure 1.

The response of the building elements, floors and walls, increase as they are becoming lighter in weight. This has come from a need to make structures more efficient and therefore cheaper. The study on which this paper is based was first prompted by enquiries from California. There, their earthquake codes demand that vertical loads are as low as possible, so buildings are built as lightweight as possible.

Users are demanding much more flexibility in the use of their instruments and their buildings. They do not want to be tied to working only when vibration producing equipment is not operating. There is also a demand to make laboratories more adaptable to change in the future, in terms of moving departments or updating laboratory instruments.

This paper covers:

- assessment of the sensitivity of instruments to vibration
- prediction of the response of laboratory floors to vibration
- recommendation of suitable criteria and design for limiting vibration in laboratories.

2 VIBRATION SENSITIVITY OF LABORATORY INSTRUMENTS

The laboratory instruments of interest range from bench top optical microscopes and balances to scanning electron microscopes (SEM) and laser interferometers. For most instruments, manufacturers' data for acceptable vibration limits are not available. Data are available for some of the more specialised instruments eg SEMs, but these vary wildly in terms of both magnitude and measurement parameter (see Figure 2). Guidelines on vibration criteria set by consultants similarly vary (see Figure 2).

The sensitivity of instruments does vary considerably. For example, are they sensitive to continuous or impulsive vibration? Is frequency content important? Are their sensitivities best described in terms of acceleration, velocity or displacement? Unfortunately, there are no clear rules. However, a gathering of data helps considerably in judging vibration sensitivity for a number of different cases.

One significant factor in assessing vibration sensitivity is the user. Different people have different perceptions of what is acceptable or not. It also depends on the resolution to which they are measuring. For example, in a pharmaceutical company a scientist may be measuring well within the capabilities of an instrument. In a research institute, the scientist may be working to the absolute limit of the same instrument, where signal to noise is poor.

2.1 Measurement Study

A measurement study was undertaken to increase knowledge of current vibration levels in laboratories (whether or not they were acceptable) and of the response of different structures to vibration.

The buildings visited were all research science buildings at universities in California. Measurements were taken on the upper (suspended) floors of the building where the vibration levels were expected to be highest. In addition, measurements were taken on instruments or on their mounting surfaces. Details were recorded of:

- instrument type
- mounting type
- floor surface
- floor structure
- relationship of transducer locations to columns, beams and walls

Recordings of vibration were made during periods of ambient vibration and with specific sources, eg footfalls or other laboratory equipment.

The laboratories where measurements were made contained instruments which could be sensitive to vibration to some extent. Comments from the users were noted as to whether the level of vibration was acceptable or not. In most cases the level of vibration was acceptable. In a working laboratory if instruments are adversely affected by a factor such as vibration, then a solution is normally found. This may mean relocating the instrument, removing the vibration source or installing a vibration isolation table.

2.2 Measurement Results

The measured results are summarised in Table 2, together with a brief description of the vibration sources and the acceptability of vibration levels.

Measurement Surface	Vibration Source	Vertical Vibration Velocity Range, mm/s rms	Notes
floor	ambient	0.015 - 0.05	Peaks in energy at 16-50Hz, corresponding to floor natural frequencies and building services forcing frequencies. General bench top instruments unaffected. High power microscope work (electrophysiology) and SEMs regularly disturbed unless secondary isolation measures included.
floor	laboratory equipment eg shakers, pumps centrifuges	0.02 - 0.16	SEMs disturbed by their vacuum pumps. General laboratory instruments unaffected, forcing frequencies generally outside floor or bench natural frequencies.
floor	footfalls	0.03 - 0.1	Peak velocities 0.1mm/s to 0.4mm/s. Instruments generally unaffected by lower vibration levels. Higher vibration levels coincided with floor and bench natural frequencies, causing disturbance to instruments of varying sensitivity.
laboratory bench	ambient & footfalls	0.01 - 0.05	Bench top instruments generally not disturbed. Higher levels occurred occasionally due to amplification by the bench. Vibration isolation tables had very high response at their natural frequencies.

TABLE 2: Summary of measured results

3 PREDICTION OF THE RESPONSE OF FLOORS TO VIBRATION

The vibration in a floor is dependent on the source input and the physical characteristics of the floor structure. For most of the sources mentioned in Section 1, there is also the transmission of the vibration through the building to consider. This is by far the most complex element. However, for these sources, there is usually some facility for vibration control at the source or along the transmission path.

Within the laboratory footfalls which put an impact directly into the floor are most difficult to control at source. Instead the response of the floor to the impact must be controlled. This will also help to control the response of the floor to the other sources of vibration.

Details of the actual prediction techniques are beyond the scope of this paper. Some of the main conclusions expressed in a qualitative way are:

Factors Reducing Response to Vibration	Mechanism for Reduction
mass	more mass results in less acceleration for the same force
stiffness	natural frequency is increased, so vibration is dissipated quicker (before the next impact arrives)
damping	vibration is attenuated quicker
loading	walls and columns form nodal points in the floor slab, restricting the number of modes which can propagate

TABLE 3: Response of floors to vibration

It should also be noted that vibration response varies across a floor slab. Near elements such as major beams or columns the floor slab is constrained. Between constraints the floor slab is more free to move, so has a higher response to vibration.

These qualitative factors have been observed in the measured results.

4 RECOMMENDATIONS FOR VIBRATION CONTROL AND LABORATORY DESIGN

4.1 Vibration Limitation Criteria

The measurement results generally supported the criteria A and B set by Gordon (Reference 1 and Figure 2). These can be applied to the design of a floor structure and are achievable on suspended floors. In general, laboratory instruments can tolerate higher levels of intermittent impact generated vibration than continuous vibration. Practical vibration limitation criteria should not aim to prevent vibration completely but to limit vibration to a level where the likelihood of disturbance is small.

Figure 3 presents Gordon's criteria and suggests how they may be extended in use to the design of other scientific laboratories containing instruments such as those discussed here. Some flexibility may be required between categories depending on the use of the building (eg research or commercial).

It should be noted that Criteria C and any vibration limits below this would be impractical to set for a suspended floor. A floor on ground is recommended.

4.2 Building Planning

Vibration control should be implemented at the building planning stage by good design practice. The main principles are:

Principles of Vibration Control Through Planning	Example Methods of Vibration Control
remove vibration sources where possible	choose a site away from major roads or railways
	limit traffic movements
keep vibration sources away from vibration sensitive areas	confine major items of building services plant to separate buildings
vibration isolate sources	locate building services plant or vibration producing equipment in the least responsive areas of the building eg ground slab

TABLE 4: Control of vibration sources

In the laboratory spaces it would be ideal to allow complete flexibility of use throughout the building. However, it is more practical to identify areas of the building and apply different degrees of vibration limitation. If all laboratory areas are designed to a good standard for vibration limitation there will be good scope for flexibility within that area. An area of the building should then be identified for the more specialist uses and the structure designed accordingly.

4.3 Structural Design

The structural design should aim to minimise the response of the structure to vibration.

Structural Element	Recommendations
structure (general)	Vary structure in terms of materials and form to limit modes of vibration.
floors	Limit size or breakup structure with beams and ribs or eg waffle slab.
walls and columns	Load-bearing preferably in order to limits floor modes. Most effective when heavy (but are then less flexible in use).

TABLE 5: Control of structural response to vibration

4.4 Instrument Mounting

Instrument mounts and laboratory benches should aim to not amplify the vibration level in the floor. (A high vibration level in the floor must not be amplified any further, but similarly a low floor vibration level must not be amplified to an unacceptable bench top level.

Instrument Mounting	Design Recommendations
general laboratory bench	Avoid lightweight or cantilevered bench tops which amplify vibration greatly. Construction rigid and stiff, with a damped bench top if possible. High natural frequency to avoid coincidence with floor natural frequency (eg >25Hz)
balance tables	Usual construction of marble or concrete provides mass and stiffness.
vibration isolation mounts and tables	Heavy, stiff table top on low frequency vibration isolation mounts. Check cost, size and flexibility of use against benefit (limited at low frequency).

TABLE 6: Control of instrument mount response to vibration

Location of instruments or benches within a laboratory is also important. Where possible they should be located on the least responsive parts of the floor. This is usually next to walls or over a major beams. This principle applies also to local vibration producing laboratory equipment. Of course vibration producing and vibration sensitive should not be adjacent to one another.

5 SUMMARY

Criteria can be set limiting vibration to levels acceptable for the use of most laboratory equipment. These criteria are achievable on suspended floors and can be predicted to some extent.

The criteria are achieved by following the procedures of:

- controlling vibration sources
- good building planning
- minimising structural response to vibration
- minimising response of benches and instrument mountings
- good laboratory planning

These principles are summarised in Figure 1.

For very specialised measurement applications, a ground slab design should be investigated at the outset to ensure minimal structural response to vibration.

REFERENCES

1 Gordon, C (1987)
The design of low vibration buildings for microelectronics and other occupancies.
Proceedings of the first international conference on vibration control in optics and metrology.

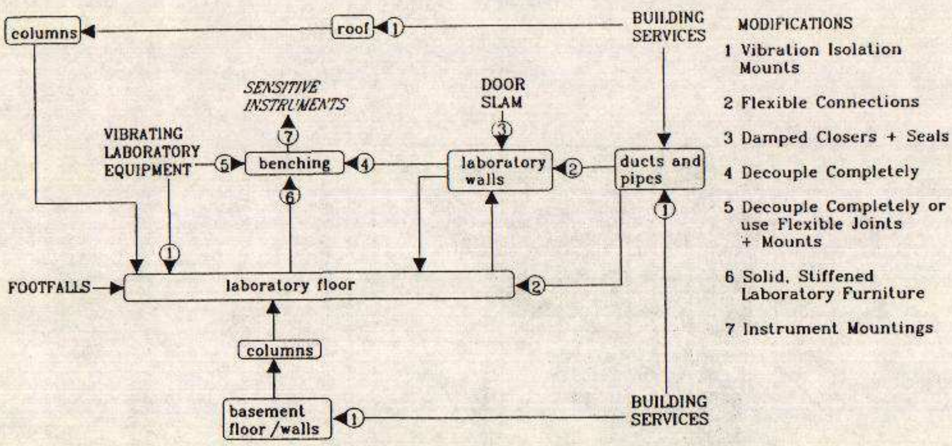
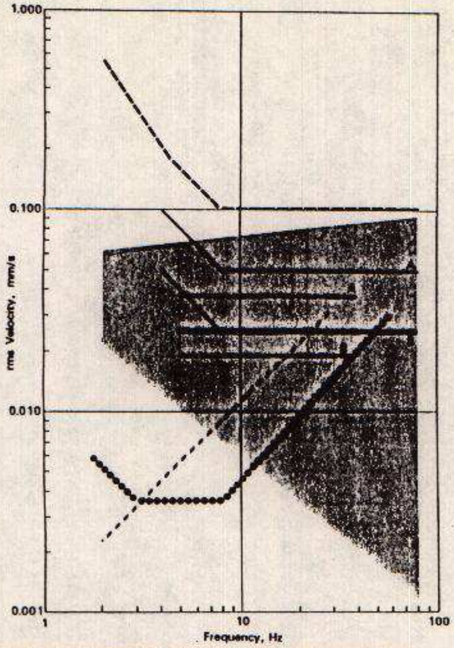


FIGURE 1: Transmission Paths of Vibration Propagation from Source to Receiver, and Points of Control (Excluding Structural Modifications)



critical working areas including precision laboratories

x400 optical microscopes

A – x100–x400 *microscopes*, microbalances
B – high power optical microscopes, 2 micron photo*lithography*

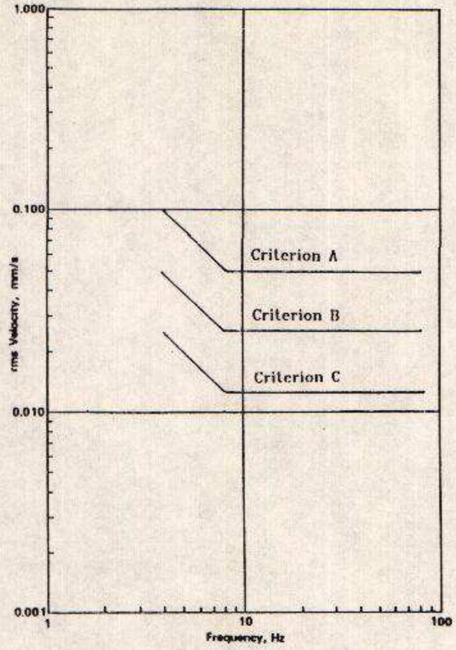
wafer fabrication

recommended environments for standards laboratories

A – optical microscopes, bench microscopes (Reference 1)
B – 3-10 micron lithography

range of criteria for the use of electron microscopes

FIGURE 2: Criteria of acceptable vertical vibration velocity for the use of sensitive laboratory equipment



Criteria A general bench top laboratory equipment, including optical microscopes and balances

B x-ray diffraction and spectroscopy
long exposure photography of microscopic samples
electrophysiology
laser optics and interferometry

C scanning electron microscopes
NMR spectrometers
scanning tunneling microscopes

FIGURE 3: Criteria for the limitation of vibration in laboratory floors for a range of vibration sensitive equipment (based on criteria by Gordon, Reference 1)