HEALTH AND SENSITIVITY

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1. INTRODUCTION

The development of diagnostic and treatment technology in healthcare increasingly brings vibration sensitive equipment into the nursing environment. There have been many studies of vibration criteria and building dynamic response. Particularly valuable practical guidance is given in References 1 and 2. This paper aims to focus on a few lessons from experience of a number of practical issues which arise in catering for equipment declared to be 'sensitive'. In particular, it looks at sources of disturbance, some of their most significant characteristics and the implications of these for the form of sensitivity criteria to be used, developed into a checklist.

2. STARTING POINTS

The NHS Health Technical Memorandum 2045 "Acoustics" (Reference 3) sets out general principles on vibration control in healthcare facilities but does not set out detailed guidance for accommodating vibration-sensitive equipment. It does, however, set overall vibration acceleration limits for "precision laboratories" at 0.005 m/s^2 RMS (z-axis) and 0.0035 m/s^2 RMS (x, y-axis) based on BS 6472, using a multiplying factor of 1. For intermittency, the Memorandum states that "it is not appropriate to make allowance for the intermittency of events, so that maximum frequency-weighted acceleration should be within the limits ... set for continuous vibration".

The criterion does not take account of variation with frequency and there is no suggestion that it can be a comprehensive limit for all sensitive equipment. Perhaps one of the more significant omissions is a lack of reference to the increasing mobility of the equipment in the form of vehicle mounted, trolley based and hand held devices, bringing diagnosis and treatment to the patient rather than vice-versa.

It is most important to start out with a rigorous approach to establishing sensitivity, not just to continuous vibration but to intermittent events, and to the determination of the implications of disturbance by vibration. Are they life threatening, seriously disruptive, regularly inconvenient or very occasionally, a minor irritant? The investment in the equipment and the building structure for this equipment can be substantial.

A clear idea of the likely threats to the equipment is a prerequisite to the establishment of vibration criteria – and there may be several criteria needed, depending on the pattern of disturbing events and operation of the equipment.

Perhaps the most difficult starting point is the identification of the 'sensitivity' of the equipment. First, there is often a surprising gap between the need for detailed vibration sensitivity criteria and the information available from suppliers which may be (a) too general (b) not understood well by local UK representatives and (c) established for circumstances very different from those intended for the case at hand. It is in this area that frustration is easily found, despite the fact that effective operation of the equipment depends on achieving an appropriate environment. There is also a huge danger of over-design if unnecessarily stringent criteria are specified by the supplier.

3. What types of equipment?

In major hospitals, some of the more 'critical' vibration-sensitive equipment might include items such as:

- Linear accelerators
- CT and PET scanners (both interventional and non-interventional)
- MRI scanners
- Lithotripters
- Flow cytomers
- Earlier PET scanner and gamma cameras

In the case of linear accelerators, vibration affecting patients may be more critical than that affecting the equipment. For some equipment, e.g. lithotripters, relative movement of the patient and machine may be more of an issue than the overall level of vibration.

In laboratories, high magnification devices, e.g. electron microscopes, need careful attention. In a variety of other locations – even the local doctor's surgery (which is expected, increasingly, to import higher technology) the provision of vibration isolation – or avoidance of amplification in benching is likely to increase.

4. Sources of Disturbance

From evaluation of a wide range of sources of structure-borne vibration, the following are perhaps some of the most common:

- Footfalls on responsive floors
- Building services equipment
- Service traffic – vehicles passing speed bumps, drains
- Loading docks
- Railway vibration
- Road traffic vibration
- Lifts and hoists
- Door slams or shutters closing (particularly if motorised)
- Other medical equipment
- Small fittings e.g. hand dryers, switchgear
- Demolition or construction works
- Trolley impacts, deliveries and collections from wards.

Before establishing and using vibration control design criteria, the input force spectra from the likely sources of disturbance need to be considered – in particular, the timing, frequency, content, rise times of impulsive sources, variability of input and compound combinations of different sources at the same time.

It is also sensible to eliminate the structure-borne noise where possible e.g. use soft seals and closures on doors, avoid recessed drains and speed bumps in or near service yards. Controls will often need to go well beyond detail. Major contributors to vibration, such as building services or railways, can lead to a need for major mitigation measures (e.g. 'floating' buildings, extensive vibration isolation of services). Broadly therefore, it is important to reduce the list of threats where they can be removed in this way.

Looking briefly at some of the variables in source characteristics, it is possible to establish a deeper understanding of how criteria should be applied.

4.1 Footfalls

There are various methods available for determining input forces from footfalls. Ideally, methods should be based on measurement of contact force time histories due to individual footfalls of subjects walking over an instrumented panel. Figure 1 shows an example of such a force impact time history. For floor responses with frequency greater than about 7Hz, the vibration is largely determined by its response to the contact impulse of each footfall. The effective impulse reduces as the frequency of a floor increases. Increasing the mass of a floor will reduce the level of vibration. Both impulsive high frequency components and structural resonances need to be taken into account in setting criteria for the equipment.

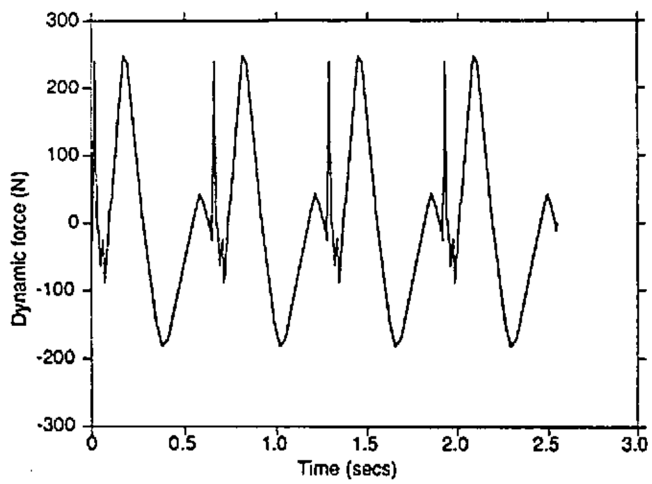

Figure 1 Example input for walking forces

4.2 Building Services

It is not customary for building services equipment suppliers to provide input force data. Running speed and standard of balance are perhaps the most valuable components of usually available data. The latter is valuable only if there is knowledge of the moving masses – not usually provided! Responses from building services equipment suppliers is often patchy.

Standard of services equipment balance – to ISO 1940 (Reference 4) – may reasonably be specified at G = 6.3 or 2.5. For projects where sensitive equipment might be threatened, G = 2.5 can be the norm.

4.3 Wind

Very low frequency lateral movement of buildings in response to wind loading may disturb some sensitive equipment, limiting its suitability for use at high level in exposed buildings. Typically the frequency range is 0.1 – 0.5Hz, which points up the importance of full frequency evaluation.

4.4 Road Traffic / Service Traffic

Broad band continuous vibration from road traffic is unlikely to disturb 'sensitive' equipment in most practical cases. The principle concern is impulsive vibration from the impact of vehicles on discontinuities in the surface e.g. expansion joints, local dips or upstands in the road, gulleys. In these cases, it is usually 'wheel hop' or vehicle rigid body responses (in the range 10 – 20Hz) that dominate the input. For relatively continuous traffic flow, this can cause substantial disturbance. For infrequent events, it may be that the very occasional disturbance could be tolerated.

4.5 Loading Docks

The assessment of impulsive forces at loading docks can only be approximate. A reasonable worst case might be a 50kg mass dropped through 1.0m, landing with an impulse duration of 20ms! Although highly variable high frequency components can be expected, the fundamental or harmonic response of the building structure may be expected to dominate.

4.6 Railways

Where railway vibration is involved, impact on sensitive equipment is potentially serious. An example underground railway spectrum which illustrates this point is shown in Figure 2. Apart from the usual factors such as spectral content of the input and railway output power, 'spikes' from rail joints and the effects of input duration on structural response, there are more tricky practical questions. How does pass-by frequency relate to acceptability disturbance? For major projects, are future changes in rail track use a threat? Will the railway operators consider contributed funds for investment into control at source and if so what liability might be picked up by a healthcare developer for the future? Change in exposure associated with the standard of track and stock maintenance should also be considered.

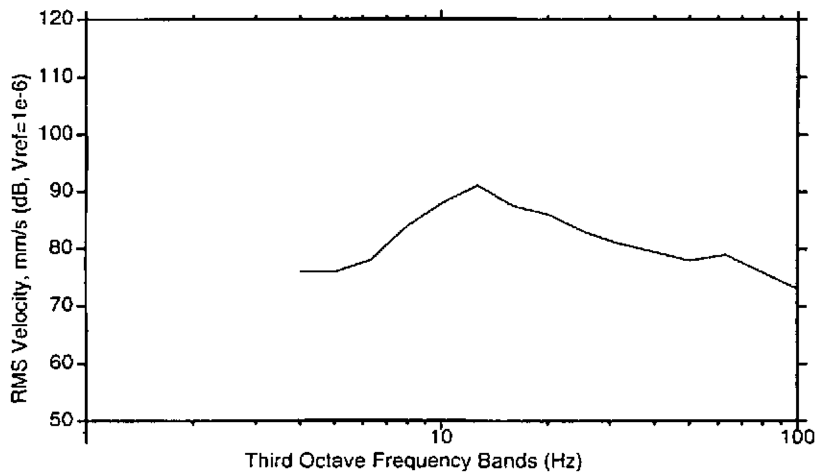

Figure 2 Example of Railway Induced Vertical Vibration at Footings

4.7 Lifts, Escalators, Small Fittings, Other Medical Equipment

It is particularly awkward to evaluate input forces for many sundry items of equipment. There is little or no published data on input forces from such equipment. For new projects it may be more practical to find other sites where the equipment has been installed. Even so, any measurements of vibration in different structures pose challenges of interpretation for the intended structures.

4.8 Demolition / Construction Work

Healthcare development projects will often involve phased demolition and construction works or be exposed to disturbance from adjacent properties. Construction noise and vibration controls may need special measures where 'sensitive' equipment is nearby (or perhaps even at some distance). Prediction of what work will or will not prove disturbing can be bypassed by arranging trials in advance. These will use simulated force input, measuring response at the equipment site and appropriate extrapolation. Other options are to use hours of working restrictions or prioritising the demolition or construction programme to make a substantial structural break from the structure housing the 'sensitive' equipment, as the first or last move.

4.9 Small Impacts

Apart from door slams, there are potentially many other impacts – from trolley, maintenance work, shutters, lift brakes and so on. An awareness of potential disturbance from these is often sufficient to develop detailed mitigation measures.

5. SENSITIVE?

For any particular case, any number of these source inputs may apply. In practice, a wide range of 'sensitive' equipment appears to operate perfectly satisfactorily in conditions which might be expected to threaten effective use. In recent studies, the author has found that provisions for sensitive equipment have ranged from isolation on substantial specialist foundations (e.g. MRI at St Mary's Paddington) to use of the same family of equipment on suspended floors in Harley Street!

In recent studies of a schedule of healthcare equipment, which included 'sensitive' and non-sensitive equipment, exhaustive enquiries to suppliers concerning vibration sensitivity produced very confused and often totally inadequate responses. There are, of course, very responsible suppliers. Some will insist on their own survey before supplying their equipment. At the other end of the scale are those that say "yes, I believe we did have a problem with vibration somewhere".

There is no doubt that there have been substantial improvements made to equipment protection. One of the dangers for designers is the use of old references for the establishment of criteria for new equipment. Experience suggests that equipment is usually reasonably well protected from common local sources of disturbance, but not major sources. Perhaps the top five sources of concern should be:

- Railways
- Loading bays, compactors and goods lift doors
- Generators
- Demolition and construction works
- Low speed building services equipment i.e. < 1000 rpm

This will of course depend on the site.

6. CHECKLIST FOR VIBRATION CRITERIA

In attempting to establish the sensitivity of healthcare equipment i.e. define criteria for its protection, based on the points noted above, the following checklist may be helpful:

- how often is the equipment used?
- if the equipment were disturbed occasionally, would the operator know?
- how serious might the implications of disturbance be?
- where has the equipment been used?
- does the supplier have criteria applicable to the precise equipment model?
- in what axes of movement do criteria apply?
- what is the frequency range of sensitivity? Relate to building services operation speeds and derivatives e.g. blade passage frequencies – also principal floor responses
- over what bandwidth are criteria stated?
- clarify parameters – max rms? peak?
- explore tolerances on the criteria
- consider the interactive response of sources and equipment protection systems

- be aware that some criteria have been given which limit vibration exposure of the patient (or, in one recent case, of the operator!)
- proximity to railways, road, loading bays, construction or demolition works
- other healthcare equipment as vibration sources?
- what undertakings in writing are made by the suppliers relative to the case at hand?

7. IMPLICATIONS

Experience is telling us that there are real difficulties obtaining good answers from the full range of sensitive equipment suppliers. This means that it is important to work with the purchasers to bring pressure on suppliers to provide more thorough guidance.

In practice, it seems that the majority of equipment can be accommodated on structures where vibration in any axis is approximately half of the threshold of human perception – in velocity terms, close to 0.05 mm/s. For the most sensitive, special mounting is likely to be needed.

Until a better pattern of technical support is available from more manufacturers, site surveys or prediction of structural vibration in new designs and written undertakings from suppliers remain the principal means of achieving successful designs.

8. REFERENCES

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