**Technical note** *A submission on this project won the AA-Bradford Excellence in Acoustics award for 2008*

# NOISE AND VIBRATION DESIGN OF THE MONASH CENTRE FOR ELECTRON MICROSCOPY BUILDING

**Matthew Stead[1], Simon Moore[1], Jon Cooper[1] and Andrew Mitchell[2]**
**1 AECOM, Level 28, 91 King William Street, Adelaide SA 5000 Australia**
**2 AECOM, Level 6, 76 Cashel Street, Christchurch 8011, New Zealand**

## INTRODUCTION

The newly completed Monash Centre for Electron Microscopy (MCEM) building is a central research facility located at Monash University, Clayton Campus, which conducts world-leading research and undergraduate and postgraduate training. Modern electron microscopes can resolve detail at the atomic level, if the effects of building noise and vibration satisfy demanding specifications.

The MCEM building provides a world class low noise and vibration environment to optimise instrument performance and is one of the most stable buildings worldwide.

The key objectives of the noise and vibration design for the MCEM project were:

- Interpretation of the client brief and electron microscope noise and vibration specifications
- Create a world class low noise and vibration environment
- Coordinated design to encompass a range of disciplines
- Quality control inspections throughout construction

## SITE

The MCEM building is located on the Monash University Clayton Campus. It is surrounded by other campus buildings, and a nearby university ring road. The ring road has a number of speed humps, which create a source of vibration when vehicles pass over them. Mechanical pumps, fans and other machinery in the surrounding buildings are also sources of vibration.

Further noise sources include vehicles using the university ring road, aircraft flying overhead, air-conditioning plant from adjacent buildings and other general activity on the Monash University Site. Noise levels on site were typically over 60 dB(A) or 70 dB(Lin).

Baseline vibration measurements showed that the ground vibration levels at the proposed site were close to the maximum that would be acceptable if the desired microscope performance were to be achieved. Hence, the building design needed to ensure that vibration levels were reduced, and not amplified in any way, particularly in the low frequency range (< 10 Hz).

All of the environmental noise and vibration sources were carefully identified and the building designed to minimise the effects due to these existing sources.

## ELECTRON MICROSCOPE OPERATION

The electron microscope uses high energy electrons whose de Broglie wavelengths are much smaller than the wavelength of visible light. Because optical microscopes are usually diffraction limited, this allows a resolution thousands of times better than a light microscope – with images that can show molecular or even atomic detail.

As shown by Gordon and Dresner [1] electron microscopes are noise and vibration sensitive for a number of reasons:

- Relative motion of microscope components and the sample itself, even on the Angstrom scale, can cause blurring and reduced image resolution.
- Long exposure times are required to receive enough electrons to generate an image at the smallest scales, so noise and/or vibration must be minimised over such time scales.
- The high voltages required for the smallest wavelengths means that a long electron beam column is required. The consequent size of the microscopes lowers the frequency of their mechanical resonances and makes them more vulnerable to low frequency noise and/or vibration.

The maximum sensitivity of electron microscopes to vibration and noise disturbance occurs, typically, when components within the electron microscopes are excited at their resonance frequencies. At these resonances, significant relative movements can occur between components.

The lowest order resonances, those in the frequency range 10 to 50 Hz typically, may be excited by vibration of the floor on which the electron microscope is supported but are not readily excited by acoustic noise, probably because of the poor coupling at these frequencies between the sound field and the electron microscope. In the few measurements that have been made of microscope sensitivity to noise, maximum acoustic 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 electron microscope is much improved. At these higher frequencies, resonances on, or within, the electron microscope are often thought to be the cause of relative movements and operational problems.

## NOISE AND VIBRATION CRITERIA

Monash University provided detailed information about the acoustic standards achieved by existing electron microscope facilities and the acoustic requirements of the proposed new electron microscopes. This information was reviewed and the most stringent acoustic criterion in each class of laboratory identified. Figure 1 summarises the noise criteria for the most sensitive A Class of laboratories in one third octave bands. This demonstrates that significant noise attenuation was required, particularly for the low frequency region (< 50 Hz), which was difficult to achieve.

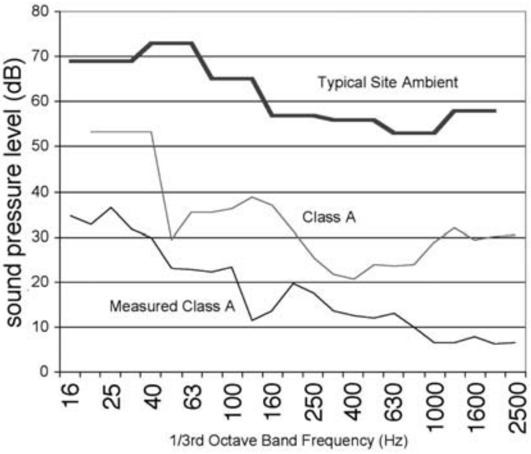

Figure 1: Measured noise levels in the most stringent (designated Class A) laboratory compared with the relevant criteria and ambient noise levels. This shows the significant noise attenuation of environmental and mechanical services noise that was achieved.

The vibration criteria were provided in a similar manner to the noise criteria. This required extensive consultation with the University who were not able to provide equipment details due to non-disclosure agreements with the microscope manufacturers. All data were provided in an anonymous format. Limited information was available on the measurement techniques used to obtain the data, which made it difficult to compare measurements with equipment criteria. As part of the project, a test method was developed to enable appropriate comparison of vibration measurement results with the equipment specifications. The vibration criterion is shown in Figure 2.

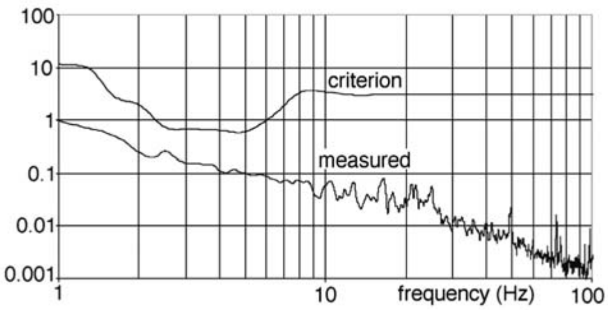

Figure 2. Measured vibration levels compared with vibration criterion for Class A laboratory.

## NOISE AND VIBRATION DESIGN

The building had a number of stringent and particular building requirements. These required non-standard constructions to achieve the design intent. As the building contractors were not familiar with these construction requirements, the construction phase inspections were frequent and timed for key stages to ensure that defects did not compromise the noise and vibration design.

Mechanical plant associated with the facility was an additional source of noise and vibration. The mechanical plant was designed to achieve air flow velocities less than 1 to 2 m.s-1 for the most sensitive lab, which required large duct cross-sections. Attenuation of the plant noise down the ducts therefore necessitated long duct runs. Most of the plant was located in a separate building to reduce vibration transmitted to the laboratories. Flexible connections were utilised to minimise vibration transmitted across the isolated slabs and isolated walls. Acoustically lined ductwork formed with steel of increased thickness and acoustic attenuators were used to control noise break-in and break-out from the ductwork entering the laboratories.

Architecturally, the most critical laboratory building structure (a box in a box) incorporates a heavy masonry internal structure (200 mm thick blockwork walls and 300 mm concrete plank roof) and, externally, multiple layers of plywood fixed to the building structure including the walls and roof.

The floor slab in the Class A and B laboratories (the laboratories with the most stringent noise and vibration requirements) is isolated from the adjacent areas. The isolated floor slab was designed such that there resonances or vibration modes are above the critical frequency range. The thickness of the floor slab was the primary variable.

Research has shown [2] that it is difficult to achieve low frequency (< 10 Hz) vibration isolation from the site.

The goal of the isolated floor slabs was to maximise vibration isolation (at higher frequencies) and to ensure that the isolated slabs do not have any resonances or vibration modes, particularly near the critical 4 Hz frequency. The design is indicated in Figure 3.

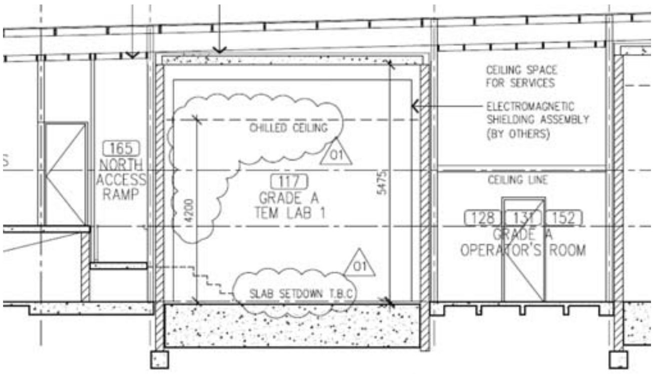

Figure 3: Cross section through an A Class Lab showing isolation between floor slabs, masonry walls and the inner laboratory floor slab.

Based on the floor slab design and measured soil properties, the design concrete slab thicknesses were up to 1000 mm thick.

Mechanical equipment has the potential to cause excessive vibration where the sensitive electron microscopes are to be installed. The major mechanical equipment types were each assessed according to power rating and normal minimum operating speed.

A schedule of vibration isolators was recommended for this project. The schedule included the spring isolator static deflection. The vibration isolator's selection depended on the distance to sensitive areas and the parameters outlined above.

## CONCLUSION

An innovative design for noise and vibration was carried out and implemented in the building's construction. The building was commissioned with noise levels lower than those typically observed in a concert hall (< 20 dB(A)) and vibration levels approximately 1000 times less than can be felt. One of the Class A electron microscope laboratories is now fully operational and is operating within the environmental parameters specified as shown in Figure 1 and 2. This allows the very high resolution microscopes to achieve 0.1 nm resolution (approaching atomic scale).

[1] Colin G. Gordon and Thomas L. Dresner, "Methods of Developing Vibration and Acoustic Noise, Specifications for Microelectronics Process Tools", Vibration Monitoring and Control, SPIE Proceedings Volume 2264, July 1994

[2] Madshus, C., B. Bessason, and L. Hårvik (1996) Prediction model for low frequency vibration from high speed railways on soft ground. J. Sound Vibr., 193(1), 195-203.

Figure 4: Site layout during construction showing laboratories (with isolated masonry walls) with isolated slabs yet to be poured.

## *Letter*

# SLINKIES AND STAR WARS SOUND EFFECTS

How to teach the dispersion relation in sound transmission? How to get a class interested in the important equation relating angular frequency ω and wave number *k* for all possible vibrational modes? And how to relate sound transmission to the atomic oscillator picture of a solid?

Seeking a demonstration, my mind returned to my childhood, and a fascinating documentary called '*SPFX*' that exposed the cinematic secrets behind George Lucas' "*The Empire Strikes Back*". The most memorable effect was the sound of the laser pistols, generated by hitting the guy-wire for a 60 m radio antenna with a spanner. In a stiff metal wire, transverse waves with higher frequencies travel faster, so the initial impulsive tap of the spanner travels up the guy-wire and back to return as the characteristic 'piow' noise of the laser pistol – a short whistling sound running from high to low pitch. A nice example of dispersion, but how to fit a 60 m radio antenna into a lecture theatre, and how to connect the resulting sound to a dispersion relation?

The solution to the first problem was to use a slinky. After all, a spring is just a huge length of wire conveniently coiled up into a much smaller package. Good results are obtained by suspending the slinky vertically with its free end just resting on the floor. You get the laser pistol sound by touching a microphone to the coil, and giving the bottom of the slinky a quick lift to make the free end tap the floor [1]. Alternatively, you can connect the slinky's top end to a soundboard, which can be as sophisticated as an acoustic guitar body or as simple as a styrofoam cup jammed between the coils.

Linking the sound to the dispersion relation is more complex, but an excellent account is given by Crawford [2]. The stiffness of the wire leads to an added energy cost for transverse waves that induce curvature in the wire. Although this bending energy is negligible in the very long wavelength limit (i.e., frequencies $\omega \rightarrow 0$), it isn't at acoustic frequencies, where the dispersion relation becomes parabolic (i.e., $\omega \sim k^2$) rather than linear. The result is an increased phase velocity for higher frequencies, and the characteristic high-to-low pitch laser pistol sound made by tapping the slinky against the floor. As to why a laser makes a noise, I'll leave that to George Lucas.

[1]. For a video of this demonstration, see http://www.youtube.com/watch?v=aqtqiuSMJqM

[2]. F.S. Crawford, "Slinky whistlers", American Journal of Physics **55(2)**, 130 (1987).

*Adam Micolich, School of Physics, UNSW*