Measurements and limits of vibration affecting the sensitive equipments of some Metrological laboratories

Tarek M.El-Basheer
Department of Acoustics, Mass and Force metrology division, National Institute for Standards (NIS), Giza, Egypt.

Hany A.Shawky
Department of Acoustics, Mass and Force metrology division, National Institute for Standards (NIS), Giza, Egypt.

Summary
Precision equipment that can be affected by vibration is utilized in industry like calibration, fabrication of precise equipment, research involving laser beams for the measurement. The precision that is required is in the order of magnitude of 10^{-6} m to 10^{-12} m. The tenuous vibration or movement can cause the equipment to go out of tolerance. Establishment of appropriate vibration criteria is essential at the metrology institutes and is not easy. Vibration can damage the metrological equipment while a high level of vibration may lead to unsatisfactory of the measurement results. Some of NIS researchers at the length metrology division have complaints arising from vibrations which cause the measurements failure. The Length precision metrology building is highly isolated from both vibration and noise but opening the door of the laboratory and also foot walking inside might be the reason for the vibration. A new reason for vibration discovered from the base which is the raised floor that present at about 0.5m above the basic concrete. Steel base was mounted on the concrete and under the optical table to prevent the vibration. Vibration analysis carried out on 1/3 octave band frequency by means of accelerometer, the velocity was measured before and after mounting the steel base. The results showed that velocity minimized to be 6.2 μm/s(2.5-25Hz)& 3.3μm/s(31.5-100Hz) after mounting the steel base. This paper aims at studying the sources of vibration at some laboratories in NIS length precision metrology division. Also, performing the 1/3 octave band frequency analyses to identify the frequencies of interest and its amplitude, then comparing with the criteria of vibration for the sensitive equipment's at the metrology institutes. To find simple and budget friendly method to control vibration at the laboratories. Also, finding the limits of vibration for metrological/research institutes like NIS.

PACS no. 43.40.+s

1. Introduction

Technological advances in both manufacturing and research regularly require or result from an expansion in precision. This expansion in precision bestows new tolerance levels on such external factors including vibration since precision at this scale can be bothered by even the smallest movement or vibration. Hence, the structural framework supporting such equipment must be designed to block vibration that meddles with the equipment's appropriate operation. New advances in methods and equipment can happen in the time the structure is designed and new advances will more likely than not happen for the duration of the life of the structure. Thus, generic outline criteria were created in the mid 1980's for situations when the particular equipment criterion was not yet accessible and these generic plan criteria have since been updated slightly. These generic plan criteria and how they identify with the more accurate equipment specifications is the subject of this research. The presentation of pneumatic disconnection and the requirements of metrology have prompted adjustment of those criteria and the presentation of new ones. We might audit the

Corresponding author: tarek31.uv@gmail.com

advancement and development of criteria, contrasting them and delegate kinds of research, metrology equipment and exercises. The two families of generic criteria:

1-Vibration Criteria (VC) developed in the early 1980s by Eric Ungar and Colin Gordon[1, 2], originally known as the"BBN"(Bolt Beranek and Newman) criteria, and subsequently promulgated by the Institute of Environmental Sciences and Technology(IEST).

2-NIST-A criterion developed in the early 1990s for the Advanced Measurement Laboratory at the U.S.National Institute of Standards and Technology (NIST)[3].The NIST-A criterion was developed for metrology, but has gained popularity within the nanotechnology community[4].

1.1. The existing Vibration Criteria

In their present form 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 1, together with the International Standards Organization (ISO)guidelines for the effects of vibration on people in buildings[5].

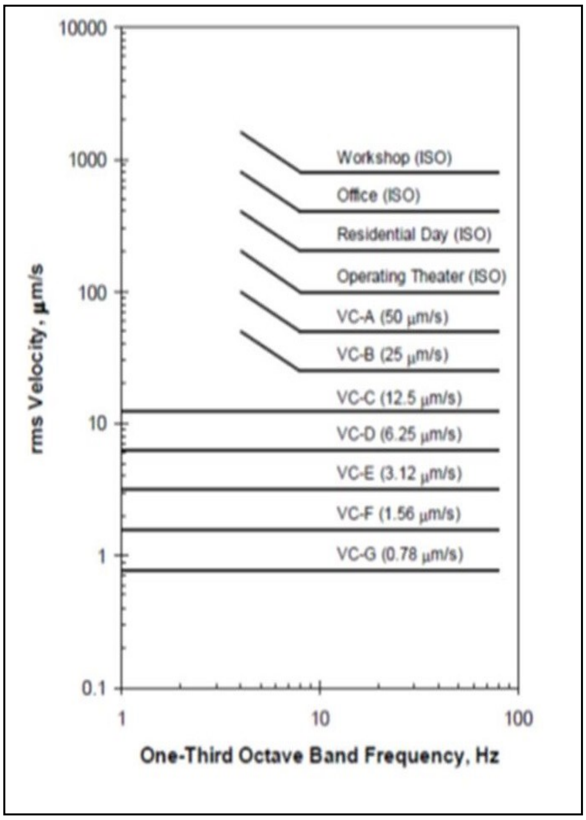

Figure 1. Generic Vibration Criterion (VC) Curves for Vibration-Sensitive Equipment - Showing also the ISO Guidelines for People in Buildings.

A general portrayal of the curves, and their proposed method of use, is as per the following:

1) The vibration is communicated in terms of its root-mean-square (rms) velocity (rather than displacement or acceleration). It has been found in different studies that while diverse items of equipment may display maximum sensitivity at various frequencies(corresponding to internal resonances), regularly these purposes of maximum sensitivity lie on a curve of constant velocity[6].

2) The use of a proportional bandwidth rather than a settled bandwidth is supported based on a traditionalist perspective of the internal damping of typical equipment components [7]. Experience demonstrates that in many conditions where sufficient layout and isolation of electrical and mechanical equipment has been given, the vibration is dominated by broadband (random) energy instead of tonal (periodic) energy.

3) The way that a portion of the criterion curves take into account more noteworthy vibration velocity for frequencies beneath 8 Hz reflects experience that this recurrence range, in many examples, lies underneath the lowest resonance recurrence of the equipment segments to which these curves apply. Relative motions between the parts are, in this manner, harder to excite and the sensitivity to vibration is diminished. The curves more stringent than VC-C doesn't unwind the requirements at frequencies underneath 8 Hz, and the curves stretch out down to 1 Hz. This change depended on the requirements of equipment with internal pneumatic vibration isolation, which much of the time moved the recurrence of most prominent vibration sensitivity from more noteworthy than 8Hz down to the range of 1 to 4Hz[7].

4) For a floor or site to agree to a specific equipment classification, the measured one-third octave band velocity spectrum must lie underneath the fitting criterion curve of Figure 1.

These equipment criterion bends have been created based on data on individual things of equipment and from data obtained from measurements made in facilities before and after vibration-related issues were settled. The bends are generic as in they are intended to apply to comprehensively defined classes of equipment and procedures. They are intended to apply to the most sensitive equipment within every classification that is defined. The criteria accept that bench-mounted equipment will be supported on benches that are rigidly developed and damped so amplification

because of resonances is restricted. They consider the way that certain sorts of equipment, (for example, SEM's) are frequently provided by the manufacturer with built-in vibration confinement.
When measuring for consistence with these criteria one must consider the "nature" of environment that is being measured:
1) When the environment is moderately constant in time and spatially uniform—generated for instance by continuously running mechanical frameworks (fan, pumps, and so forth.) or by intensely traveled highways —it is by and large sufficient to quantify the "energy average" vibration levels. Levels can be estimated at various locations, if the zone being evaluated is expansive, and the aggregate data can be abridged statistically. It is viewed as sensible to characterize the VC execution in light of the "average plus one standard deviation" level at every frequency.
2) When the environment isn't constant in time—impacted for instance by walkers (footfall excitation), or close by trucks—it might be important to quantify the "maximum rms" (sometimes called "peak hold") vibration levels.

1.2. Other Criteria

Various distinctive criteria for vibration-sensitive tools have been produced throughout the years. Maybe a couple of them are genuinely generic in the sense that they can be utilized to grasp the necessities of an extensive variety of tool types.
Medearis Time Domain Method
Medearis[8] recommends generic criteria for vibration-sensitive equipment based on "time domain" as opposed to"frequency domain" peak-to-peak displacement measurements. The frequency range of measurements is not defined. He suggests limits of 2.5 microns (100 micro inches) and 7.5 microns (300 micro inches) for microelectronics facilities and science laboratories, respectively. His criteria are not reconcilable with the fact that most tool makers, recognizing that their equipment is not equally sensitive at all frequencies, provide siting specifications in the form of frequency domain spectra.
Ahlin Response Spectrum Method
Ahlin[9] is currently developing a new measurement and evaluation methodology based on the concept the response spectrum, used extensively by structural dynamicists in seismic design engineering.

2. Materials and method

2.1. Units of measurements

Velocity is the most important metric for the measurements. Vibration level is measured as oscillation about a fixed point and recorded in [Velocity (rms):µm/s].

2.2. Measurement Instrument

Detecting and measuring vibrations requires the use of an accelerometer (B& K 4371) of specifications as follow :
-Frequency range (0.1 – 12.000Hz)
-Temperature (-74-250^{o}C)
-Weight (~11gm)
-Sensitivity (0.995pC/ms^{-2})
-Resonance frequency (15.000Hz)
The accelerometer was connected to electronic instrument used to amplify, analyze and store vibration data. Vibration is measured with an accelerometer placed at the vibrating surface on the table on which the sensitive equipment is placed. A vibration analyzer model: vb5, Manufactured by comment (Newzeland). It is of high accuracy and calibrated at NIST(USA) and is used to measure the vibration in different places.

2.3. Mounting the accelerometer

The method of mounting the accelerometer to the measuring point is one of the most critical factors in obtaining accurate results from practical vibration measurements. We used a thin layer of bees-wax for sticking the accelerometer into place.

2.4. Vibration Standard

Standard for vibration analysis :
ISO 8569 -1996"Mechanical vibration and shock-measurement and evaluation of shock and vibration effects on sensitive equipment in buildings."
ISO 4866-1990"Mechanical vibration and shock – vibration of buildings – guidelines for the measurement of vibrations and evaluation of their effects on buildings."
ISO 2041-1990"Vibration and shock - vocabulary"

2.5. Test rooms Description

The room dimensions range from 4-5 m (width)* 5.5-7 m (length)* and 3-4m (height). The optical/normal table dimensions are ~(2.5 x 1.5 m) and its height is (1.2m) from the room floor. The rooms lie at the ground and first floor which is higher than the road surface ~ 4.5m.

2.6. Measurement locations

The type of sensitive equipment's and laboratories at which the measurements performed can be listed in table1.

Table I: laboratory name and number

Laboratory	*Laboratory No.*	*Sensitive equipment*
Gauge block lab.	Lab.1	Gauge block & laser interferometer
Length Primary calibration lab.	Lab.2	Primary calibration system for length using laser interferometer
Mass Lab.	Lab.3	Sensitive & micro-balances
Acoustics lab.	Lab.4	Calibration system for accelerometers

2.7. Calibration before measurements performed

Exciter calibrator type B&K 4294(DFM – traceability) was used for calibration of Accelerometer before the measurements.

2.8. Uncertainty of measurements

In order to get a statistical reliability an uncertainty calculation method in vibration measurement is presented based on values obtained by the measurement system.

3. Results and discussion

3.1. Vibration measurements

Velocity (µm/s) versus 1/3 Octave band frequency (Hz):

Since that one of the main and very interesting things for the metrological laboratories is to maintain the condition of measurements constant as possible. Because that this condition may cause errors in the measurements especially for the very sensitive equipment's. National institute for standards NIS is not only a metrological institute but also it is a scientific institute in which the researchers perform scientific researches that help industries and society. So it is important to keep temperature, humidity and vibration levels at a certain permissible level. So, all the building and design of NIS buildings are highly isolated from vibration and this in order to save the sensitive equipment's. The idea arises when some of researchers suffered from vibration exist at some laboratories.

So, selection of some laboratories (with highly sensitive equipment's) was performed to measure and analysis the vibration exists.

Figure 2 show the velocity versus 1/3 octave band frequency within the range 2.5-100Hz. Then the results were compared to the VC criteria limits to judge if the activity in this laboratory was in the limits related to its criteria or not.

Lab.1 is the laboratory for calibration of gauge blocks. It is clear from the figure that the velocity level may reach to 53µm/s especially at low frequencies. So, it is very important to find a way for treatment of the vibration exists to help the researcher to do scientific research on the laser interferometer which will be placed at this room. The reason for this problem is due to the raised floor above the main floor. Where during the motion at the laboratory we felt vibrations. So that suggestion of mounting four steel bases from the concrete main floor to the legs of the optical table to minimizes the vibrations (see figure 3). Then analysis performed to find if the vibration lowered or not. From figure 2 one can find that the velocity level became lower than the before treatment. Where the velocity reaches to (6.2 µm/s within frequency range2.5Hz up to 25Hz, 3.3 µm/s from 31.5Hz up to 100Hz) and in comparison of this level with the VC curve (figure 1). It is clear that this velocity level is related to VC-D , thus the laboratory may be classified as in the higher criteria VC-D in which optical devices may be used. Each floor structure has a natural frequency that is a function of its span, stiffness, and mass. Typical floor systems fall in the frequency range of 3 to 8 hertz (Hz). If the forcing-function frequency caused by walking is close to the natural frequency of the floor framing, nuisance vibration will likely occur. While this vibration is typically not perceptible on a physical level, the ramifications to sensitive laboratory equipment can be significant.

In order to find the limits of vibration at the laboratories of NIS , measurements were carried out at different buildings and laboratories which have sensitive equipment's. So that measurements were performed at mass, acoustics and primary length different laboratories.

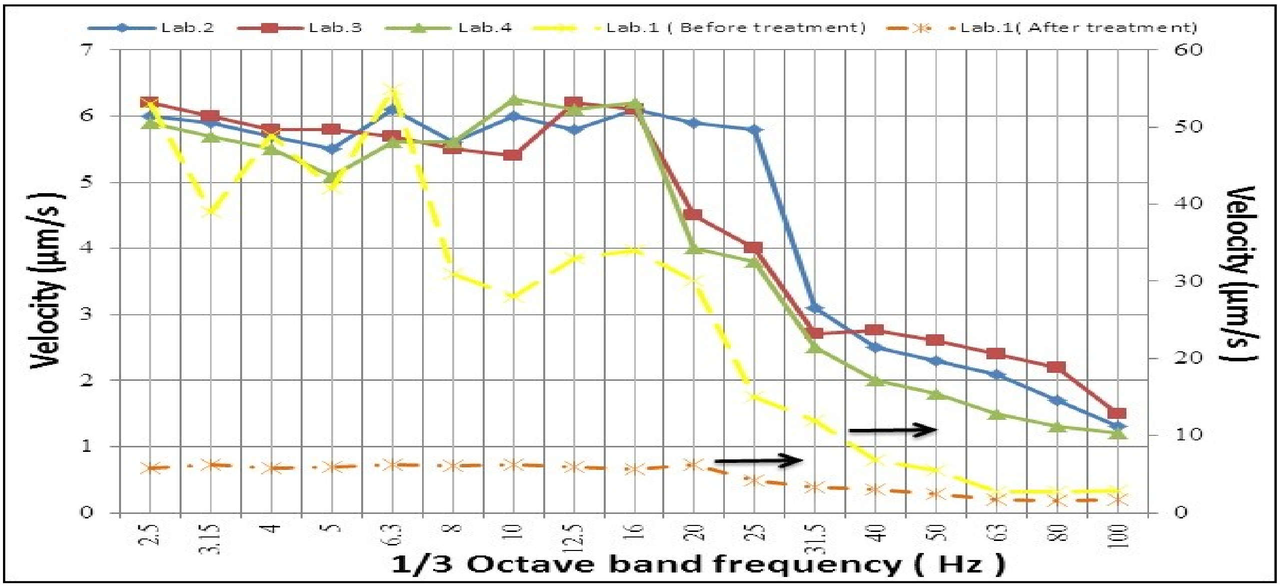

Figure 2 : Velocity versus 1/3 octave band frequency

Figure 3 : Shows the suggested steel base mounted from the concrete to the raised floor at Lab.1. (Dimension of steel base is: length=250mm , width=250mm & height = 300mm.)

It is clear from figure 2 that the three laboratories which exists at the main building of NIS have velocity limits in the order of magnitude of 6.25 µm/s(VC-D)up to 25Hz, 3.3µm/s from 31.5Hz up to 100Hz. This means that all of the three laboratories belong to the VC-E when comparing with the vibration criteria curve.

Since the structure-borne vibrations are the main concern for researchers. In addition, acoustical noise, electromagnetic fields, radiation, air flows, particulates and temperature fluctuations are disturbing phenomena, which lead to strict requirements for the research facilities. Research institutes (e.g.NIS) demand facilities which are suitable for a wide variety of instruments and equipment. This has led to generic requirements of the floor quality. Implementation of these requirements results in a flexible layout and multifunctional utility of the laboratories. From all the measurements at the laboratories, we can find that the conditions at NIS laboratories are suitable for research institute and of course good condition for metrological laboratories.

From the results we can put the limits of vibrations above which the sensitive equipment's may be out of tolerance depending on the metric velocity (µm/s). Within the frequency range from 2.5 to 25 Hz (6.25µm/s) and from 31.5 to 100Hz (3.3 µm/s).

3.2. Uncertainty of measurements

When designing and performing measurement, one has to consider following effects and restrictions affecting the obtained measurement result:

The measuring instrument can suffer from errors due to aging, wear, or other kinds of drift, poor readability, noise (for electrical instruments) and many other problems.

Imported uncertainties can occur-calibration of the instrument has an uncertainty which is then built into the uncertainty of the measurements.

Operator skill is very important, as some measurements depend on the skill and judgment of the operator.

The environment affects the measurement in different ways, e.g., temperature, air pressure, humidity and many other operational conditions can affect the measuring instrument or the item being measured.

Vibration measurements uncertainty is usually evaluated using procedure provided in " Guide to the Expression of Uncertainty in measurement"- GUM[10].

Ways to Estimate Uncertainties

There are two approaches to estimate the uncertainty-'Type A' and 'Type B' methods. Uncertainty evaluations of both types are needed in most measurement situations. Anyway, the overall uncertainty budget covers all uncertainty sources, regardless the method used for their evaluation:

Type A Evaluation (u_A) : Uncertainty estimates using statistics (usually from repeated readings).

Type B Evaluations (u_B) :Uncertainty estimates obtained from other information sources. This could be information from past experience of the measurements, from calibration certificates, manufacturer's specifications, from calculations, from published information and from common sense.

Combined Standard Uncertainty

After calculating the standard uncertainties for all the sources of uncertainty in your measurement then the total uncertainty in the measurement, called the combined standard uncertainty, is given by the square root of the sum of the squares of all the uncertainties in the measurement.

$$U_c = \sqrt{(u_A)^2} + (u_B)^2 \quad (1)$$

Coverage Factor

To increase the level of confidence in the results to the 95%, calculated to extend standard uncertainty is obtained when the coverage factor K = 2.

Expanded Uncertainty

The calculation of expanded uncertainty of measurement will be given by the product between the combined uncertainty Uc and the Coverage factor k95% .

$$U_{Exp.} = k * Uc \quad (2)$$

Table II. The following table shows the key contributions and uncertainty budget for the measurements.

Symbol	*Description*	*Type*	*Distribution*	*Divisor*	*Uncertainty %*
$U_{Repeat.}$	Repeatability	A	Normal	1	0.2
$U_{Reprod.}$	Reproducibility	A	Normal	1	0.3
$U_{Acc.}$	Calibration certificate of Accelerometer	B	Normal	2	0.5
U_{Drift}	Drift	B	Rectangular	√3	0.05
$U_{read.}$	Readout	B	Normal	1	0.1
$U_{Temp.}$	Temperature	B	Rectangular	√3	0.03
Uc= ±0.62%					
(k) Coverage factor=2 (U) Expanded uncertainty=2*0.62=±1.25%					

4. Conclusions

As the world of technology heads from the "micro" scale toward the "nano", the building environment in which the measurements, fabrication and calibration performed takes on a singular importance. NIS provides the trust in measurement science, therefore it is important that NIS scientists stay competitive with standards bodies in other countries as well as stay abreast of advancement in technology. The role of NIS is to (1) provide the researchers with a big leap forward with regard to research, which they had needed for quite, some, time; and (2) provide the leadership in measurement science at Egypt and Africa. Therefore it is important to maintain the sensitive equipment's at an environment causes no errors in the measurements. From the obtained results, we can conclude that:

The NIS Advanced Measurement Laboratories has been heralded as one of the best research environments to avoid vibration that affected to sensitive equipment's. Vibration limits for most of NIS metrological laboratories which have sensitive equipment's are rms vibration velocity~ 6.25µm/s(freq.:2.5-25Hz) and 3.3 µm/s (freq.:31.5-100Hz) and this is consistent with VC curves VC-(E&D). Steel base can effectively minimize the vibration velocity levels to belong to the VC(D & E). The uncertainty value is ±1.25% which is a good value for this type of vibration measurements.

Acknowledgment

The corresponding author want to thank the persons who help during the measurements: Hatem Khalaf(Acoustics) , Hussein Mustafa &Hanem Mohamed (Length) and Shaker & Ahmed(Mass).

References

[1] E.E. Ungar, C.G. Gordon, Shock Vibration Information Center Shock Vibration Bulletin (1983).

[2] E.E. Ungar, C.G. Gordon, Vibration criteria for microelectronics manufacturing equipment, INTER-NOISE and NOISE-CON Congress and Conference Proceedings, Institute of Noise Control Engineering, 1983, pp. 487-490.

[3] A. Soueid1a, H. Amickb, T. Zsiraia, (2005).

[4] H. Amick, M. Gendreau, C.G. Gordon, Facility vibration issues for nanotechnology research, Proceedings of the Symposium on Nano Device Technology, Taiwan, 2002.

[5] I.O.f. Standardization, Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements, The Organization, 1997.

[6] H. Amick, Journal of the IES 40 (1997) 35-44.

[7] E.E. Ungar, D.H. Sturz, C.H. Amick, Sound and Vibration 24 (1990) 20-27.

[8] K. Medearis, Journal of the IES 38 (1995) 35-44.

[9] K.A. Ahlin, Response equivalent peak velocity: a new method for description of vibration environment for sensitive equipment in buildings, Optomechanical Engineering and Vibration Control, International Society for Optics and Photonics, 1999, pp. 118-126.

[10] I. BIPM, I. IFCC, I. IUPAC, OIML.(1993) Guide to the Expression of Uncertainty in Measurement. International Organisation for Standardization, Geneva, Switzerland, ISBN 92-67-10188-9, 1993.