



VIBRATION ISOLATION TREATMENTS FOR COORDINATE MEASURING MACHINES

David R. Meredith, P.E.
Kinetics Noise Control, Inc.
6300 Irelan Place
Dublin, Ohio 43017

This paper was presented at:

- SME (Society of Manufacturing Engineers), June 1993, Nashville, Tenn
- International Conference on Structural Dynamics, Vibration, Noise, and control, December 1995, Hong Kong.
- InterNoise '96 (1996 International Congress on Noise Control Engineering), August 1996, Liverpool, U.K.
- This paper is also printed in "Mfg.", which is the Brown and Sharpe in-house technical news and engineering magazine. Volume 3, Issue 1, 1996.

Coordinate measuring machines (CMM) have recently become popular as a quick and accurate means of dimensionally checking a manufactured part. CMM technology permits the user to confirm that a specific quality control dimensional standard has been maintained. The measuring speed and accuracy of CMM's have been improved over the past several years, and CMM manufacturers are continuing to work towards improving both of these operating parameters.

The recent increases in measured accuracy have forced the awareness of a potential problem area for many CMM's – external vibration. Compromises in measured accuracy can occur if a CMM should be placed in a location so that the base of the CMM is excited by the floor upon which it is installed.

This paper shall serve to provide an overview of the subject of vibration isolation treatments for CMM's. A quantity of five (5) subject areas will be presented:

1. The need for vibration isolation.
2. Sources of external disturbing vibration.
3. Manufacturer's vibration criteria levels.
4. Accurate determination of environmental vibration levels.
5. Vibration isolation system types and characteristics.

The Need for Vibration Isolation

If all components of a CMM, including the item to be measured, were to vibrate in unison at a specific frequency, amplitude and orientation, it is likely that no degradation in measured performance would result. To the CMM, this situation would represent the same condition as no vibration excitation whatsoever since all parts of the CMM would be synchronized relative one to another. It is only when components begin to move out of phase with each other that accuracy problems begin to occur.

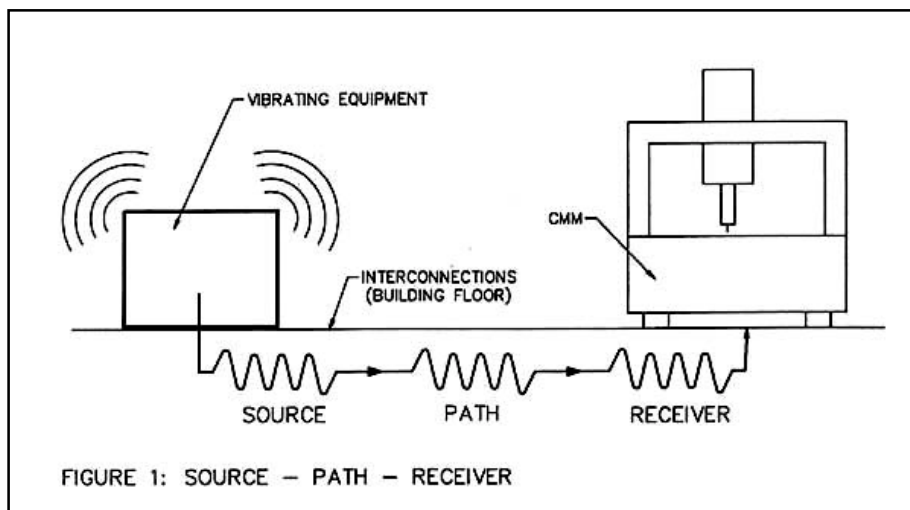
If two items vibrate and are out of phase, their position in space will vary as a function of time. More important, the relative distance between the two items will also change. If the measuring probe of a CMM is vibrating out of phase with the part to be measured, the apparent result will be a variation in the digital readout of the CMM with a corresponding decrease in usable measuring accuracy. Further, poor repeatability will also become a concern since the relative distance between CMM components will fluctuate, making it difficult to repeat the same measured value. The result becomes inaccurate and unreliable measurements.

The influence of vibration on CMM accuracy in the vertical "Z" axis is typically less severe than in the horizontal "X" and "Y" axes, due to the relative stiffness of the measurement probe arm. The unsupported length of the CMM probe arm is generally longer horizontally than vertically, resulting in a greater tendency to vibrate when set into motion. External disturbing vibration may therefore be suspected if a specific CMM exhibits acceptable performance in the vertical axis, but varies in the horizontal axes.

CMM users will often attempt to compensate for external vibration by confining their most accurate measurements to "good" times of the day. As an example, a CMM user in a manufacturing facility may elect to conduct his critical measurements during a production lunch break, shift change or other similar time during the day that plant activity is at a minimum. In an extreme example, all CMM usage was intentionally scheduled in a manufacturing facility to occur during a third shift at a time when the rest of the plant was shut down and inoperative. While the above example may provide a solution to the problem of external disturbing vibration, it obviously compromises the value of the CMM to the user.

Sources of External Disturbing Vibration

Vibration transmission components can be neatly categorized into one of three (3) broad categories (Figure 1):





- A. Source – The equipment or activity which generates the disturbing vibratory energy.
- B. Path – The structure into which the vibration is transmitted and is carried to the:
- C. Receiver – The equipment or individual which is affected by the vibration.

Isolation to the vibratory energy is most effective the earlier in this sequence it can be accomplished. It is more advantageous, for example, to isolate the source of the vibration than to isolate the receiver.

- A. Source – Vibration can be created by a large multitude of different sources. In a typical manufacturing facility, some of the more common vibration sources may include:
 - 1) Production equipment (stamping presses, forging hammers, reciprocating air compressors, shaker feeders, conveyor systems).
 - 2) Heating and ventilation equipment (out-of-balance fans, blowers, pumps).
 - 3) External rail or highway traffic in the vicinity of the installation.
 - 4) Lift truck or product moving equipment within the plant.
 - 5) Airborne vibration due to aircraft flyover.
 - 6) Shipping and receiving areas (pallets being dropped, truck impacts into the dock).

The most effective method of minimizing a vibration problem is to control the source of the vibrational energy. As an example, if the operation of a blanking press causes accuracy problems for a CMM in the immediate area, the best method available to control this vibration is to stop the operation of the press. Should this not be possible, the placement of vibration isolation mounts beneath the press helps to reduce the amount of vibrational energy transmitted into the floor structure.

While source isolation is the most effective method of controlling vibrational energy generated by a piece of production equipment, the concept begins to become limited when other potential sources are considered. The installation of dock bumpers may help to control vibration caused by truck impacts, for example, but source isolation becomes an impractical means of isolation of vibration due to low flying aircraft.

- B. Path – For most installations, the path for vibrational energy is the structure common to both the source and the receiver. The soil beneath and between the blanking press (source) and the CMM (receiver) is a common example of the path that vibration can traverse. Other paths can include building structures, piping



and ductwork. Airborne vibration (i.e., noise) may also result in vibration problems in extreme cases. The installation of a CMM within a climate controlled room will typically solve most airborne noise problems since the walls of these rooms generally exhibit high airborne noise reduction capabilities.

The most common method of controlling vibration through path modification is to simply increase the distance between the source and the receiver. The location of a CMM as far away as possible from potential vibration sources is an effective method of vibration control. Unfortunately, for many installations, exactly the opposite is required. The CMM may need to be located adjacent to a piece of production equipment which is producing the item which the CMM must measure.

Other path modifications may involve the use of inert material between the source and the CMM. Sand, as an example, will not transmit vibratory energy as readily as clay soil. The placement of a CMM on top of a pit filled with sand might provide required vibration attenuation capabilities (if problems with compaction and settling could be controlled).

An interesting example of this concept taken to an extreme involved a CMM user who dug a trench moat around his CMM. This trench was then filled with a silicone fluid in an attempt to control the vibration path to the CMM. While certainly a novel approach, the end result was less than satisfactory due to the energy path beneath the bottom of the trench in the subsoil which was not affected by the presence of the trench.

- C. Receiver – This technique, although less effective than either source or path control, is the most common method of isolating a CMM. The placement of the CMM on an isolation system will provide a stable support for the CMM. However, the vibratory energy is still being produced by the source and is still present adjacent to the CMM installation site.

The isolation of the receiver is a popular vibration treatment since the cost of the preparation of a suitable CMM support platform can be included in the initial installation budget.

The design of an appropriate CMM foundation must address a number of concerns. Both existing and future potential vibration sources must be included in the design analysis. Long-term stability of the isolation media used (if any) is also critical to the success of the installation.

It is important to keep in mind that a “vibration free” CMM foundation cannot be obtained. Even if extremely efficient vibration isolation products are used, there will always be “some” vibration present. It is the goal of the engineer to ensure that the residual vibration at a CMM foundation location is below the criteria put forth by the CMM manufacturer.

A number of CMM manufacturers have undertaken R&D projects to harden their CMM's against structureborne vibrations. This concept involves the stiffening and



strengthening of the internal CMM components in order to render them less susceptible to vibratory motion. The addition of vibration isolation or dampening products during CMM assembly can also result in the capability of a CMM to properly perform in a “hostile” vibration environment. The CMM manufacturer should therefore be consulted in the event of a vibration control problem to determine the possibility of a vibration retrofit kit for their CMM. This potential modification to a CMM is beyond the scope of most users to install and should be coordinated solely through the manufacturer or their agents.

Manufacturer’s Vibration Criteria Levels

CMM manufacturers must qualify the maximum amount of vibration which their machines are capable of withstanding. This vibration criteria level is an important part of a customer’s pre-installation site review. A clear understanding of the site vibration requirements prior to the installation of the CMM can avoid potential problems and accuracy/repeatability questions during the use of the CMM.

The quality of the manufacturer’s criteria level specification can vary. Some manufacturers have subjected their CMM’s to a series of shaker tests and have carefully developed a detailed vibration specification. Other manufacturers have reviewed past installations and have generated a criteria level based upon what appears to be working well at existing CMM sites. However the method of determining the specification, it is important that both the manufacturer’s representative and the customer have a clear understanding of the site vibration requirements prior to the consideration of the installation of a new machine.

Manufacturers’ vibration criteria levels can be subjectively grouped into five (5) broad categories:

1. “Bad” – No objective specification (i.e., “CMM must be installed at a quiet, vibration-free location.”).
2. “Fair” – A vibration level, expressed in units of either acceleration, velocity or displacement, which is independent of frequency (i.e., “CMM must be installed at a site whose measured floor displacement shall not exceed 2 microns peak-to-peak.”).
3. “Good” – A vibration level which is dependent upon frequency (i.e., “CMM must be installed at a site whose measured floor motion shall not exceed 10 mm/sec-sec RMS acceleration in a frequency range from 2-10 Hz, and shall not exceed 20 mm/sec-sec RMS acceleration at frequencies above 10 Hz.”).
4. “Better” – A vibration level, dependent upon frequency, which is expressed for each of the machine’s three axes. As previously discussed, the sensitivity of a



CMM to external vibration can vary with the axis of orientation and a quality specification will reflect this.

5. “Best” – A vibration level, dependent upon frequency, expressed in three axes, which qualifies the measured accuracy of the CMM. A CMM may exhibit a compromise in its measuring accuracy if it is installed at a location with excessive vibration. This compromise, however, may be acceptable to the customer if his required measuring accuracy is less than the maximum potential CMM capabilities. A vibration specification which recognizes and documents this potential accuracy trade off permits the user to objectively qualify and review potential CMM installation sites.

Accurate Determination of Environmental Vibration Levels

It should now be apparent that an important part of any pre-installation site qualification involves the accurate determination of the groundborne vibration levels. This analysis may also be used to qualify and to rank several potential CMM location sites within a given facility.

This determination of vibration levels is most easily accomplished through the performance of a vibration survey at the proposed CMM location. A set of three axes vibration transducers is placed on the floor of the test site. These transducers produce an electronic signal which is proportional to the vibration levels experienced by the transducer. This electrical signal is typically recorded on a tape recorder or data collector for future playback and analysis. In this manner a permanent record of the vibration levels is generated and can be maintained for future reference. The data is then analyzed by frequency and compared to the manufacturer's vibration criteria specification. A review of this comparison data can thus be made to confirm the site suitability. The data also assists the isolation system designer in the correct design and selection of the vibration isolation products (if needed) which will satisfy the project's requirements.

The performance of the vibration survey is not a service which should be taken lightly, for it requires specialized equipment, knowledge and experience. A frequent difficulty involves the use of an inappropriate vibration transducer. Most conventional accelerometers are ill-suited for the monitoring of low-level ground vibrations. Low frequency seismometers or geophones offer a number of benefits and are recommended for this application. A comparison between accelerometers and seismometers will highlight some of their differences:

Accelerometers

Solid state
Small size
Light construction
Low output
Sensitive at high frequencies

Seismometers

Moving mass
Large size
Heavy construction
High output
Sensitive at low frequencies



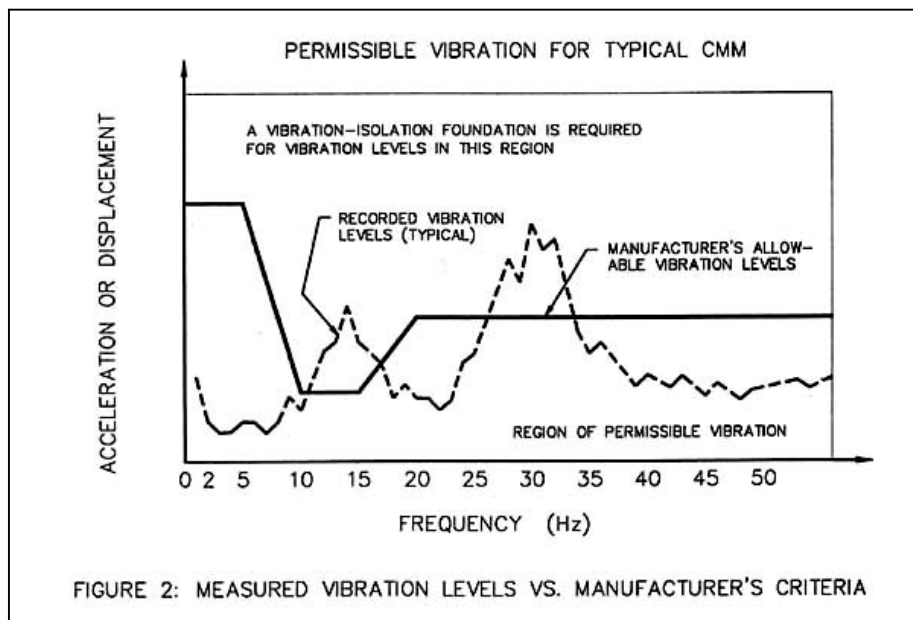
May be triaxial
Critical to cable used
Must be attached to floor

Single axis (3 req'd)
Cable insensitive
Can rest on floor

The primary frequency range of interest for vibration isolation is at frequencies below 40 Hz, and it is in this range that seismometers are capable of providing optimum data.

A vibration site survey should occur over a time span of at least 30 minutes. During this time all relevant disturbing sources should be individually cycled in order to permit the review of the influence of each potential source. The large amount of data which could be gathered for longer duration tests (i.e., over an entire eight-hour production shift) is typically redundant to the data gathered during a shorter test. The exception to this rule concerns the potential for short-term transient sources that cannot be scheduled (for example, a railroad train passing by the installation site). In this case a long-duration test is recommended in order to ensure that all transient data is captured.

The results obtained from the analysis of the survey data should be presented to the user in a manner analogous to the manner in which the manufacturer's criteria levels are represented. This permits the overlaying of the measured data onto the same graph as the criteria, thus permitting easy comparison (Figure 2).



It is important to remember that the results of the survey will be reviewed by non-technical people. The use of "dB" as a unit of vibration measurement, as an example, should be avoided since it requires the user to mathematically convert to the units chosen by the manufacturer. Further, "dB" is primarily used to describe airborne sound pressure levels and confusion is possible if it is used to classify



vibration levels. More sophisticated data units, such as power spectral density, may be useful for the vibration practitioner, but most users are not likely to be familiar with these units. The type of averaging (peak, RMS, peak-to-peak) must also be expressed and compatibility with the manufacturer's criteria should be maintained.

Vibration Isolation System Types and Characteristics

Vibration isolation systems can be used in conjunction with a CMM in order to reduce site vibration levels to below the manufacturer's criteria. They can permit a CMM to be placed in a high vibration environment yet still allow the CMM to obtain full accuracy and repeatability.

The field of "active" vibration control has been the focus of much research and development work over the past several years. Active vibration control involves the use of force-generating transducers which are fed by an amplifier and a vibration monitoring device. The transducers produce a vibratory force equal in frequency and amplitude to the vibration present at the vibration monitoring device, but 180 degrees out of phase. In principle this application of an equal but opposite vibratory force results in a net cancellation of the disturbing vibration at the installation location.

Active vibration control holds much promise for future development. The field remains somewhat experimental today, however, with an expensive first cost for the required hardware and an unproven field track record. For these reasons, it is likely that a practical vibration isolation system installed today would involve the use of conventional passive isolators. In the future, however, it is anticipated that active vibration control will become an attractive isolation option.

Passive vibration isolators can take several forms, but they share several common characteristics. They are comparatively easy to design, install and troubleshoot. They have been proven in thousands of installations, and their initial first cost is typically modest. For most installations, little or no upkeep maintenance is required. It is therefore reasonable to expect that passive isolators will continue to be popular for years to come.

Passive isolators can be grouped into three (3) broad categories:

1. Pads – Vibration isolation pads are typically manufactured from neoprene, fiber glass, felt, cork or other similar compressive material. Their natural frequencies generally fall within a range from 5 Hz to 30 Hz, and they can be manufactured in a variety of sizes, thicknesses and load-carrying capabilities. Pads are the least expensive type of isolation material to purchase, and they exhibit a high damping rate when excited at their natural frequency.

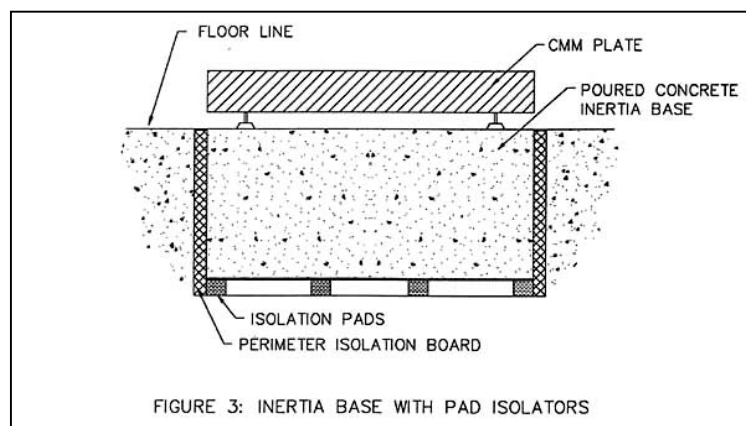
An important concern with the use of pads involves the stability of pads over time. Many types of pads will continue to creep and compress when statically loaded,

resulting in a continuous change in elevation for the isolated equipment. In addition, some pad material (primarily neoprene) exhibits age stiffening, so that the natural frequency of the pad slowly increases over time. This can result in the isolation capabilities of the material becoming less effective as the CMM ages and begins to “loosen up.” It is obviously important that the user closely review and discuss these issues with potential pad suppliers.

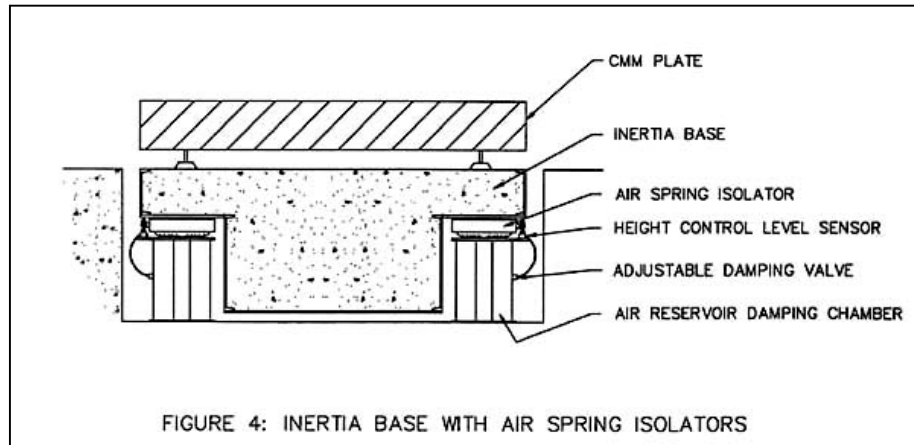
2. Springs – Helical coil springs are available in many different sizes and load-carrying capabilities. They are classified in terms of deflection under load; a 1” spring (for example) is a spring which compresses by 1” when supporting its rated load. The natural frequency range for coil springs is typically from 6 Hz to 1-1/2 Hz, corresponding to deflections from 1/4” to 4”. Since deflection is related to the spring’s natural frequency, the determination of a spring’s natural frequency becomes straightforward. Springs exhibit a fairly low damping rate so amplification at resonance may become a user concern. Although typically more expensive than pads, they are nevertheless fairly economical. Properly manufactured coil springs do not suffer from creep or settling and are generally manufactured within housings which are equipped with isolator adjustment bolts to facilitate equipment leveling.

3. Air Springs – Air springs, the most expensive type of passive isolators, offer the user a number of unique features. With natural frequencies typically falling in the 3/4 Hz to 4 Hz range, they are the softest and most efficient isolator style available. Since the air pressure within the spring is easily varied, the user can quickly adjust the height, load-carrying capacity and stiffness to meet installation requirements. The air spring system can be equipped with automatic height-sensing valves which will automatically adjust the air pressure in the air springs to compensate for isolated equipment load changes (i.e., CMM bridge travel) and to maintain a preset equipment level. Air spring isolators also can be designed to provide an adjustable damping rate which permits a high degree of user “fine tuning” to match unique installation requirements.

An important part of any isolation system is the use of a suitably designed inertia base. An inertia base is a platform upon which the isolated equipment sits and which is supported by the vibration isolators. The inertia base is typically manufactured from concrete or heavy steel and is designed to match the support requirements of the isolated equipment (Figure 3).



Inertia bases provide a number of benefits to the user. The base lowers the overall isolated center of gravity of the equipment which minimizes the tendency for the equipment to “rock” on the isolators. When the isolated equipment/base vertical center of gravity coincides with the isolator centerline, the isolator rocking modes are decoupled, which results in an extremely stable installation. The heavier the inertia base, the less equipment motion for a given vibratory input. An inertia base also provides a stiff, firm foundation for the isolated equipment to rest upon, comparable (if so designed) to a poured concrete slab on grade. Bases can be designed with pockets to accept alternate isolator types in the event that the job site isolation requirements should change in the future (Figure 4).



Pre-fabricated inertia base concrete pouring form frames offer a number of functional advantages over concrete formed-in-place bases. The inertia base frame can be manufactured off site from steel perimeter members complete with all required internal concrete reinforcing bars. Equipment foundation mounting plates or anchor bolts are easily prelocated and incorporated into the inertia base frame. Wide flange beams or similar framing members can be readily designed into the base frame as required to stiffen the completed base. Field forming and coordination problems are minimized since the only installation field work required to complete the base installation is to place the inertia base frame into position and to fill it with concrete. Single-source isolation system responsibility is obtained when the vibration isolator supplier is also responsible for the design and construction of the inertia base.

The selection of the correct vibration isolator group (pads, springs or air mounts) as well as the unique isolator natural frequency requirements within an isolator group is best accomplished through the use of the measured site vibration data and the manufacturer’s criteria specifications. A comparison of the site vibration levels to the manufacturer’s specifications will allow the establishment of the required isolation efficiency at those frequencies where the measured data exceeds the criteria. This information then allows an isolator’s isolation efficiency curve to be used to establish the natural frequency requirements of the isolation material. A review of a vibration isolator manufacturer’s technical product literature or discussions with their representatives can then pinpoint the specific isolation products which are appropriate for the project.



Sufficient factors of safety should be considered in the selection of the vibration isolation products for a specific project. Potential future increases in equipment accuracy requirements or disturbing site vibration levels should be reviewed and anticipated. Amplification at isolator resonance can become a concern if the site vibration frequencies should coincide with the isolator natural frequency. The amount of potential amplification will vary with the isolator type and this isolator characteristic should be reviewed and understood during the design process. It is beneficial to design the inertia base to be able to accept different isolator types for the possibility of future isolation requirement changes. Isolation performance changes can then be readily accomplished without significant inertia base rework.

Conclusion

The review of a CMM manufacturer's vibration criteria requirements is an important part of the pre-installation site qualifications. An accurate measurement of a potential CMM location's ambient vibration levels should be performed and the vibration site survey's results are to be compared to the CMM's manufacturer-specified criteria. Vibration isolation treatments can then be selected and installed in order to meet the project requirements.