AN AMERICAN NATIONAL STANDARD

ASME B89.4.1a-1998

ADDENDA

to

ASME B89.4.1-1997
METHODS FOR
PERFORMANCE EVALUATION OF
COORDINATE MEASURING MACHINES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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Following approval by the ASME B89 Committee and ASME, and after public review, ASME B89.4.1a-1998 was approved by the American National Standards Institute on March 3, 1998.

Addenda to the 1997 edition of ASME B89.4.1 are issued in the form of replacement pages. Revisions, additions, and deletions are incorporated directly into the affected pages. It is advisable, however, that this page, the Addenda title and copyright pages, and all replaced pages be retained for reference.

SUMMARY OF CHANGES

This is the first addenda to be published to ASME B89.4.1-1997.

Replace or insert the pages listed. Changes listed below are identified on the pages by a margin note, **(a)**, placed next to the affected area. The pages not listed are the reverse sides of the affected pages and contain no changes.

Page	*Location*	*Change*
ix	Contents	Revised
46	5.5.7.1(g)	Revised
	5.5.7.1(h)	Subparagraphs (1), (2), and (3) revised
	5.5.7.3(h)	Revised
49, 50	6.2.1	Third paragraph revised
57–58.3	Appendix C	Revised in its entirety
78–78.2	Appendix I	Sections I6, I7, I8, and I9 added

Tables

Appendices

(a)

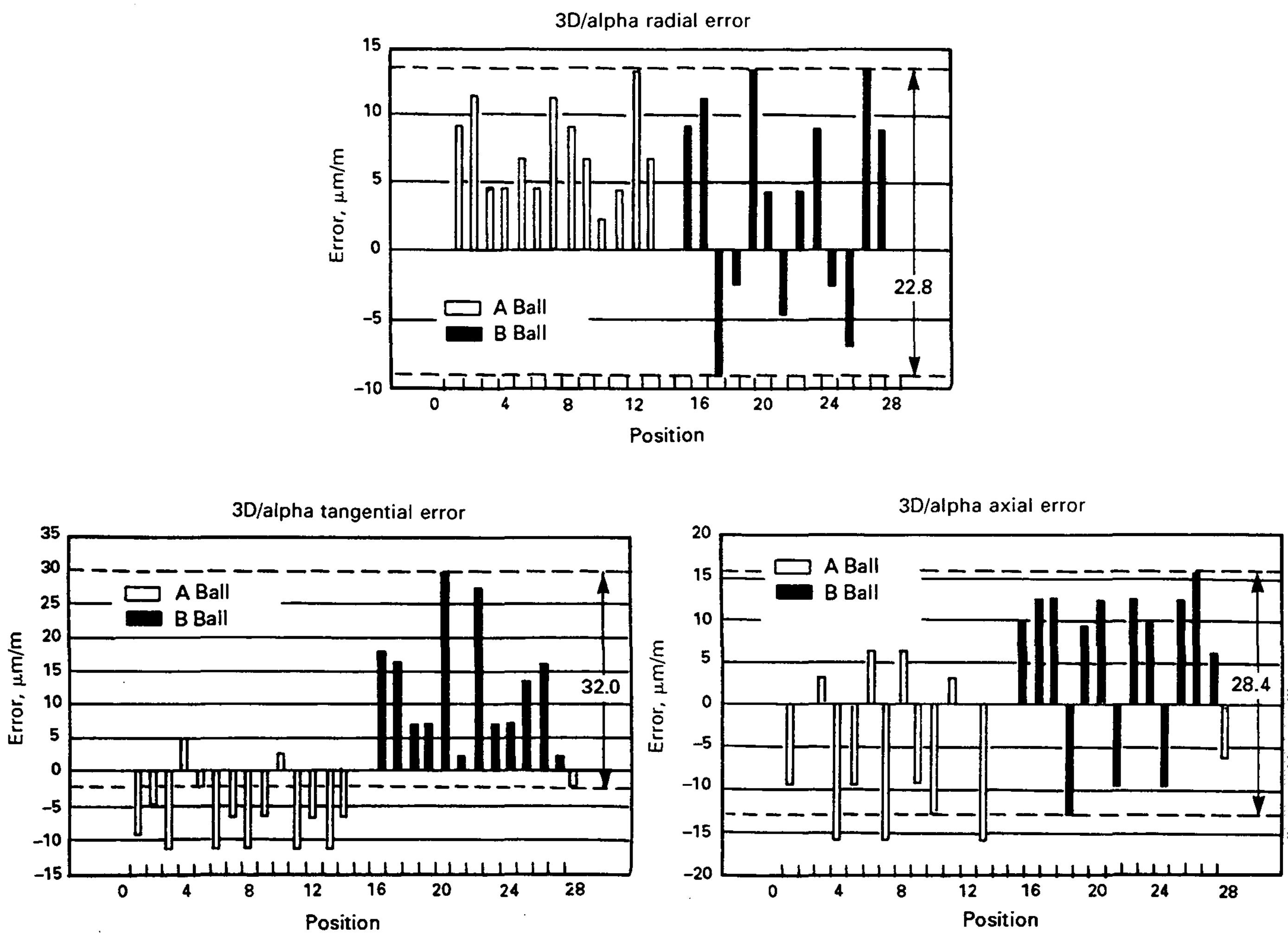


FIG. 36 TYPICAL RESULTS OF A VOLUMETRIC PERFORMANCE TEST FOR A DCC MACHINE WITH A ROTARY AXIS
(The 3D/alpha radial, 3D/alpha tangential, and 3D/alpha axial working tolerances are clearly labeled on the graphs.)

(d) The load at any specific contact point will be no greater than twice the load of any other contact point.

(e) The center of gravity of the machine load must lie within the CG location zone.

(f) The specific test load must fall within acceptable machine load limits, as defined by the Load Concentration Chart (Fig. 3).

The following steps should be taken for the test procedure.

(a) Place the test weight on the machine.

(b) Perform the repeatability test as described in this Standard (para. 5.3), with the exception of location. Location is optional in this test.

(c) Perform six ball bar measurements, as physical constraints allow, selected from the following eleven user-selectable positions:

(1) (four) 3D diagonals (as available);

(2) planar diagonal (front);

(3) planar diagonal rear (opposite orientation);

(4) planar diagonal (top);

(5) planar diagonal (left side);

(6) planar diagonal (right side — opposite orientation); and

(7) two orthogonal linear axes.

WARNING: Omission of 3D diagonals may prevent seeing the full effect of loading.

(d) Remove weight.

(e) Repeat (b) above (repeatability test).

(f) Repeat (c) above (ball bar measurements).

(a) *(g)* Perform a repeatability analysis: results of tests (b) and (e) shall not exceed the stated repeatability specification.

(a) *(h)* Perform volumetric analysis:

(1) range of readings of test (c) shall not exceed stated machine volumetric performance specification;

(2) range of readings of test (f) shall not exceed stated machine volumetric performance specification;

(3) the difference between a measured length in test (c) and the measured length from the same position in test (f) shall not exceed 50% of the machine volumetric performance specification.

5.5.7.2 Optional Procedure (Laser or Gage Block). Follow the procedure described above using a laser interferometer, gage block, or other equivalent device as the measured artifact. Analyze all data per para. 5.5.7.1.

5.5.7.3 Rotary Table Machine Procedure. For a rotary table machine, the procedure is as follows.

(a) Calibrate the rotary table in an unloaded mode.

(b) Place weight on the machine in compliance with the guidelines of para. 5.5.7.1 above.

(c) Perform the repeatability test as described in para. 5.3, with the exception of location. Location is optional in this test.

(d) Perform the volumetric performance test for DCC machines with a rotary axis (para. 5.5.6) using positions listed in column A1 of Table 2.

(e) Remove weight.

(f) Repeat (c) above (repeatability test).

(g) Repeat (d) above (volumetric performance test).

(a) *(h)* Analysis: results of tests (c), (d), (f), and (g) shall not exceed the stated machine performance specifications for repeatability, radial, tangential, and axial (3D/alpha) error.

NOTE: It is recommended that a weight with simple geometric form be used for testing purposes to reduce potential difficulties in calculating the CG location.

5.5.8 Volumetric Performance Requirements. Volumetric performance, as calculated in paras. 5.5.2, 5.5.3, 5.5.4 (if applicable), 5.5.5 (if applicable), 5.5.6 (if applicable), and 5.5.7 (if applicable) shall not exceed the supplier's specifications, derated as specified in paras. 4.2 and 4.3, if applicable.

5.6 Bidirectional Length Measurement Capability

5.6.1 General. The preceding tests have produced a meaningful picture of the measurement system performance; however, some errors, such as undue machine or probe hysteresis and improper probe compensation, have not been fully analyzed since no two-sided length measurement has yet been performed. The following tests remove this deficiency by requiring the measurement of a gage block of a convenient length, in four positions in the machine work zone. Three of these positions are roughly aligned with the machine axes, and the fourth position is user-selectable. It is recommended that this fourth position not be aligned with any machine axis. The length of the block shall be within the range of at least 25 mm (approx. 1 in.) to 100 mm (approx. 4 in.), with the default value being 25 mm (approx. 1 in.). The gage block shall be calibrated in accordance with the requirements of para. 7.3.1.

Before performing these tests, the machine probe shall be calibrated and qualified according to the supplier's recommendations for normal operation of the machine when measuring parts. Qualification on the gage block to be used for this test is specifically excluded. The measurements for this test are also to be performed using the probing parameters, probe approach rate, probe approach distance, and settling time specified for normal operation in Fig. 1A.

5.6.2 Measurement Procedure — Bidirectional Length Measurement. The gage block conforming to the requirements of para. 5.6.1 above shall be rigidly mounted in the work zone of the machine on a fixture that allows probing access to the faces of the gage block for the four measurement positions in turn. The mean temperature of the gage block and the appropriate machine scale(s) may be measured during this gage block measurement process for each position, using a thermometer conforming to the requirements of Section 7. The exact location of the gage block in the work zone is not critical; however, it is recommended that this position be near the location in the work zone where parts will most commonly be measured. After mounting and alignment, which may be center is approximately 100 deg. from the pole of the test ball in a direction parallel to the shank attached to the stylus ball, 12 equally spaced on the equator with the pattern rotated about the stylus shank 10 deg., 12 equally spaced around the ball with the stylus center approximately 60 deg. from the pole and rotated about the stylus shank an additional 10 deg. relative to the previous pattern, 12 equally spaced with the stylus center approximately 30 deg. from the pole with the pattern again rotated an additional 10 deg., and finally, one on the pole of the test ball. This situation is depicted in Fig. 37, in which the different probe positions are shown with dashed lines and labeled positions 1 to 5. The default test for manual machines is the measurement of 49 points distributed as uniformly as practical over the measurable portion of the test ball.

On direct computer-controlled machines, the probe shall be vector-driven toward the test ball center for each touch, provided this is normal for the machine when measuring parts. On driven manual and free-floating manual machines, where possible, one axis should be locked and the remaining axes moved to contact the ball in order to accurately hit the test ball. In all cases, the supplier's probe approach distance, probe approach rate, and settling time, as given in Fig. 1A, shall be used.

6.1.2 Data Analysis — Point-to-Point Probing. From each set of 49 readings for each stylus, a sphere center is computed using the supplier's recommended algorithms. From this center a radius is then determined for each measurement point. The minimum radius is subtracted from the maximum radius to produce the point-to-point probing performance for each of the stylus lengths. If the result obtained for a particular stylus is less than the working tolerance for the test, then the testing is discontinued for that stylus and the result reported. If the result for any stylus is greater than the working tolerance, then the test shall be repeated. If the new results agree to within the working tolerance for repeatability (para. 5.3), then the second set of data is discarded and the first set used for the analysis. If they do not agree, then a third set shall be taken. If this agrees with either of the two previous sets, then the first of the agreeing sets shall be used in the analysis. If no agreement to within the working tolerance for repeatability is obtained after three measurement sequences for any given stylus, the test is discontinued and the fault determined and corrected. After correction, all of the tests described in this section, even those for stylus lengths that were previously in tolerance, shall be repeated.

6.1.3 Probe Approach Tests — Optional. Many machines/probe systems exhibit vastly different characteristics depending on the probe approach distance and the probe approach rate. For the machine user desiring to use more than one value of these parameters, this test of the machine performance is recommended. The procedure is the same given in paras. 6.1.1 and 6.1.2, except that this test is performed for two different probe approach distances and probe approach rates. The working tolerance for point-to-point probing is specified for each of these options.

6.1.4 Point-to-Point Probing Performance Requirements. Point-to-Point probing performance, as calculated in paras. 6.1.2 and 6.1.3 (if applicable), shall not exceed the supplier's specifications, derated as specified in para. 4.3, if applicable.

6.2 Probing Analysis — Multiple-Tip Probing

In addition to the probing errors highlighted in para. 6.1.1, CMMs that use multiple stylus tip positions can have additional errors. These errors can be due to a number of sources including the uncertainty in location of each of the tips caused by tip calibration errors or by the errors associated with the use of an orienting head or probe changer. This is true for all multiple-tip system configurations, including:

(*a*) systems using multiple styli connected to the CMM probe, such as star clusters;

(*b*) systems using orienting heads;

(*c*) systems using probe or stylus changers; and

(*d*) systems using heads with multiple probes.

The common element of these systems is that different tips or tip locations are used to inspect a workpiece without any recalibration of the tips. As a result, it is important to understand any additional errors which might be contributed by these systems.

6.2.1 Method of Test — Multiple-Tip Probing. **(a)** The calibration ball diameter and all system configuration dimensions in this Section are default values. Other dimensions may be substituted and it is recommended that this be done if there is any concern that the configurations required to measure actual workpieces are substantially different from the default values.

A precision reference ball conforming to the requirements of para. 7.3.3 shall be rigidly mounted on the workpiece supporting surface in the work zone of the machine on a fixture that allows access by the machine probing system. The 6 mm (approx. 0.25 in.) diameter test sphere used in the point-to-point probing test (Section 6.1) may be used for this test. Any position may be chosen for this mounting with the default position being the TVE position as specified in Fig. 1.

Five different probing tip positions shall be used to perform this test. These positions can be created by using a stylus configuration with five tips, five different orientations of an orienting head, or through the use of a probe or stylus changing system using five different tip positions. Two of the probe tip positions shall be on a line perpendicular to the ram axis. Two more shall be on another such line displaced 90 deg. The fifth position shall be on a line parallel to the ram axis through the intersection of the first two lines. The default stylus length, including any extension members, shall be 50 mm (approx. 2 in.) when using any of the above systems or combination of the above.

The user is allowed to specify any test pattern that contains 25 points. These 25 points shall be probed on the test ball as equally spaced as possible and cover as much of the sphere surface as practical. The 25 points shall be taken using five different tips or tip locations and each set of five points probed by each tip shall also be as widespread as possible. As an example, these five points could be four points around the equator of the sphere (assuming the pole position is directly in line with the stylus shaft supporting the tip) plus a point directly in line with the stylus shaft.

6.2.2 Data Analysis — Multiple-Tip Probing. From the set of 25 readings, a sphere center is computed using the supplier's recommended algorithm. From this center a radius is then determined for each measurement point. The minimum radius is subtracted from the maximum radius to produce the multiple-tip probing performance. If the result obtained is less than the working tolerance for the test, then the result is reported. If the result is greater than the working tolerance, then the test shall be repeated. If the new result agrees with the result of the first test within the working tolerance for the repeatability (para. 5.3), then the second set of data is discarded and the first set is used for the evaluation. If they do not agree, then a third set should be taken. If this agrees with either of the two previous sets, then the first of the agreeing sets shall be used in the evaluation. If no agreement to within the working tolerance for repeatability is obtained after three measurement sequences, this test is discontinued and the fault determined and corrected. After correction, the repeatability test (para. 5.3.3) and all of the tests described in this section shall be repeated.

6.2.3 Multiple-Tip Probing Performance Requirements. Multiple-tip probing performance, as calculated in para. 6.2.2, shall not exceed the supplier's specifications, derated as specified in para. 4.3, if applicable.

7 TEST EQUIPMENT

7.1 Temperature

The time constant of thermometers shall be no more than one-tenth the cycle time of the highest frequency component of the temperature variation of interest in a test. The time constant is the time required for the thermometer to indicate 63.2% of its final change due to a step change in temperature.

The resolution of thermometers need be no greater than one-tenth the amplitude of the lowest-amplitude component of temperature variation of interest in a test.

Thermometers shall be calibrated by suitable means to an accuracy of ±0.1°C over the temperature range of use.

7.2 Vibration

For the purposes of this Standard, relative motion shall be measured using a high-resolution, undamped displacement indicator. Resolution of 0.1 μm (approx. 0.000004 in.) or better is recommended.

7.3 Displacement

7.3.1 Gages. Step gages and gage blocks shall be calibrated to within one-fifth the working tolerance for the repeatability specified for the CMM. Indicating gages shall have a resolution of no more than one-fifth the working tolerance for repeatability. All gages shall be calibrated following the supplier's recommendations.

7.3.2 Laser Interferometer. A laser interferometer conforming to the requirements of this Standard shall have a frequency stability such that this long-term stability represents an error of less than one-fifth the working tolerance for repeatability of the machine (in meters), divided by the length of the longest machine axis (in meters). The resolution of such a system shall be better than one-fifth the working tolerance for repeatability.

APPENDIX C
CMM SITE VIBRATION MEASUREMENT

(a)

(This Appendix is not part of ASME B89.4.1-1997 and is included for information purposes only.)

C1 SCOPE

The purpose of this Appendix is to recommend vibration measurement instrumentation and procedures for measuring vibration at CMM installation sites. Vibration levels should be measured at the proposed CMM site(s) to compare to allowable site vibration limits established by the CMM supplier. This Appendix also defines the instrumentation and suggested procedures to establish vibration on the CMM for additional analysis. This Appendix does not, however, address the determination of vibration sources or the reduction of vibration levels. Such determination is usually involved and requires the knowledge of vibration specialists.

C2 DEFINITIONS

This Appendix is intended to be self-defining and is written for individuals with an engineering background. Definitions for specific vibration terminology may be found in IES-RP-CC024.1, Measuring and Reporting Vibration in Microelectronics Facilities, published by the Institute of Environmental Sciences.

C3 VIBRATION ACCEPTANCE CRITERIA

The CMM supplier is to provide site vibration levels of acceptability. Below these levels the CMM can operate successfully, and above these levels problems may occur. Each CMM manufacturer has different formats and levels of acceptance. The type of vibration measurements to be taken will depend on format and vibration units used by the CMM supplier. Based on the type of criteria, the vibration specialist should determine the necessary measurement units, frequency range, measurement locations, and instrumentation.

C3.1 Units

Vibration is characterized by amplitude versus time or frequency. The amplitude can usually be defined in displacement, velocity, or acceleration. Depending upon the type of criteria, the amplitude ordinate can be defined in either the time domain or the frequency domain.

C3.1.1 Ordinate Units. Since the CMM is a dimensional measurement tool, units of displacement are most useful in relation to CMM performance. However, velocity and acceleration are also appropriate parameters for measuring CMM site vibration.

C3.1.2 Abscissa Units. The use of time or frequency for the abscissa will depend on the acceptance criteria format of the CMM supplier. Time based criteria are referred to as a Time History, which provides measurement of transient or very low frequency vibratory events such as beat signals. The frequency domain allows measurement over a very short time range, which provides an ability to diagnose many dynamic events.

C3.2 Format

As defined in B89.4.1, the supplier provides, as part of the machine specification, a statement of acceptable vibration. This criterion should be provided by the supplier, or listed as part of the CMM specification form, if used. At least two criteria format options are presented: Frequency Function and Time History.

The supplied acceptance criteria will define the format in which to present the vibration data for ease of comparison.

C3.2.1 Frequency Response Function. This type of information is specified as a vibration amplitude as a function at specific frequencies. The criteria are usually presented as allowable vibration amplitude versus frequency in Hertz. The frequency range may vary from supplier to supplier. In general, seismic vibrations are applicable over a range of 0 (DC) to 100 Hz. Vibration levels have large dynamic range, and it is sometimes helpful to present amplitude data in logarithmic scale. If decibels are used, the standard reference values must also be used.

C3.2.2 Time History. These measurements represent the vibration during the time period of interest. The supplier should specify a maximum peak-to-peak acceptable vibration level and a time period over which it applies. The vibration level can be in units of displacement, velocity, or acceleration.

C3.2.3 As an alternative, the CMM supplier may choose to evaluate vibration related CMM performance degradation on the actual installation site, and compare it with an acceptable level as a basis.

C4 INSTRUMENTATION

This Section describes various instruments required to perform on-site vibration measurements. Various types of sensors, signal conditioners, recorders, computer programs, and signal analyzers are available for use in acquiring this data. It is not the intent of this Section to single out any particular equipment manufacturer, but to recommend types of equipment which meet the requirements of this Appendix.

C4.1 Transducers

Many types of transducers exist for various types of vibration measurements. The measurements specified in this Appendix require a specific accelerometer or a specific type of velocity transducer.

C4.1.1 Seismic Accelerometers. The two most important requirements for the accelerometer are frequency response and sensitivity. Site vibration measurements generally require low frequency and high sensitivity. The minimum frequency response linearity should be less than 1 Hz, preferably 0.5 Hz. The maximum frequency response should be greater than 100 Hz. The sensitivity of the accelerometer should be 10 Volts/g or greater, where g is equal to 9.8 m/sec^2 (386 in./sec^2).

C4.1.2 Velocity Transducers. These sensors are also referred to as geophones. The sensitivity of the geophone should be 0.4 V/mm/sec (10 Volts/in./sec) or greater. The frequency response linearity requirement of the velocity transducer is the same as the accelerometer, 0.5 Hz to 100 Hz.

C4.2 Amplifiers and Signal Conditioners

The transducers require amplifiers and signal conditioners. Most seismic accelerometers require an amplifier, but some models may have built-in electronics that do not require signal conditioning. Velocity transducers may require amplification and signal conditioning, depending upon the sensitivity and signal-to-noise ratio. It is the responsibility of the vibration specialist to use the proper signal conditioners.

C4.3 Signal Recording/Analysis Instruments

The type of instrumentation to use will depend on the type of criteria and format that have been provided by the CMM supplier. The frequency function criteria requires a Fast Fourier Transform (FFT), a Dynamic Signal Analyzer, and, in some cases, a Digital Recorder. Time History data can be acquired with an oscilloscope, a digital recorder, a FFT analyzer, or a frequency analyzer.

C4.3.1 FFT Signal Analyzers. This type of analyzer offers the most sophisticated means of measuring vibration, by providing the greatest amount of information about the vibration signal. In most cases, this additional information is necessary to understand the vibration environment. Many types of FFT analyzers exist, from many different manufacturers. One and two channel units, hand-held, and PC-based are formats readily available. It should be noted that using a data recorder as specified below will require the use of an FFT analyzer after the data are acquired. It is the user's responsibility to understand their instrument's capabilities and limitations.

The following section offers guidelines for FFT analysis configuration and specifications.

(a) *Noise floor.* -100 dBV/root Hz.

(b) *A/D resolution.* The resolution of the analog-to-digital converter should be at least 12 bits. The better analyzers will have 16 bit A/D resolution.

(c) *Dynamic range.* The dynamic range should be at least 70 dB. Better spectrum analyzers will have higher dynamic range.

(d) *Frequency resolution.* This parameter as it applies to the analyzer is denoted in number of lines over which the analysis range is divided. Most analyzers can have selectable resolution from 100 lines to 1600 lines. The resolution in Hertz is calculated by dividing the frequency range by the number of lines. For example, a 0 to 100 Hz frequency range acquired with a 400 line analysis will have 0.25 Hz (100/400) resolution. The frequency resolution used must be compatible with the resolution of the frequency response criteria. If the criteria are defined at every 1 Hz, the data must be acquired with a 1 Hz resolution. The overall frequency resolution will also be dependent on the transducer frequency response. This information should be complied with and modified only when the CMM manufacturer's specification requests otherwise.

(e) Anti-aliasing filter. This filter prevents incorrect reporting of frequency components due to under sampling of higher frequency signals. This filter is found on most (if not all) FFT analyzers. It should always be used.

(f) Averaging. Most analyzers have this feature. When used, it reduces the effects of transient events such as personnel or vehicular activity. It is recommended that 10 averages be taken for all measurements. Some spectrum analyzers have various types of averaging functions such as linear, rms, peak hold, or exponential. Linear or summation averaging should be used.

(g) Window functions. This feature is used to force a generalized vibration signal into discrete time domain periods. When window functions are not used, the frequency response of the vibratory signal is incorrectly distributed throughout the frequency range. There are many types of window functions. The most popular are Hanning, flat top, and uniform. The Hanning window provides the best compromise in amplitude and frequency accuracy. Other windows provide excellent amplitude accuracy and poor frequency accuracy, and vice versa. The Hanning should be used for all measurements specified in this Appendix.

C4.3.2 Data Recorders. For ease of gathering vibration data in the field, the use of a multi-channel data recorder is found to be useful and convenient. Such an instrument allows for three or more channels of data to be recorded simultaneously while providing a permanent record for archives and verbal data annotation during specific events. Additionally, the recorder allows a record of the real time response which can be most useful. The data can then be processed at a later date using in-house data reduction techniques such as FFT analyzers or signal analyzers specified in this Appendix. The recorder format must be digital and use Digital Audio Tape (DAT) because of the excellent signal to noise ratio and dynamic range as compared to analog tape.

C4.3.3 Oscilloscopes. This piece of general laboratory equipment may be easily obtained to make an initial set of Time History readings. Most facilities have an oscilloscope and personnel who can operate the equipment, allowing users to take baseline readings for themselves. The oscilloscope is also useful for viewing beat signals, transient events, and hourly and daily vibratory changes. The oscilloscope should be set to AC coupled and free run triggering. The vibration amplitude is determined by viewing the signal and determining the peak-to-peak voltage amplitude, and using the transducer sensitivity for converting to appropriate amplitude units.

C5 TEST PROCEDURE

The procedures for making vibration measurements are fairly simple once the appropriate analysis equipment is selected and configured as required.

C5.1 Calibration

At a minimum, the vibration measurement equipment should have been calibrated by a qualified laboratory, traceable to NIST, in the past 12 months. Site calibration comparison testing of the transducers at the start of the testing is required.

C5.2 Transducer Mounting

For all measurements, the transducers should be mounted directly and firmly to the floor or a common interface for measuring three mutually orthogonal axes. Such mounting arrangements are referred to as triaxial. Some transducers incorporate three mutually orthogonal axes in one device. When this mounting arrangement is used, all three channels should be acquired simultaneously. Time independent triaxial measurements should not be performed because simultaneous orthogonal responses will not be achieved.

In case of measurements of floor tilt motions (rocking), two sets of sensors are mounted at a designated distance for simultaneous measurements in two orthogonal vertical planes.

C5.3 Measurement Location

In general, the transducers should be mounted in the general area where the CMM will rest. This area should encompass the outer envelope of the CMM plus 3 m (10 ft) beyond this foot print on a uniform floor surface, or at the CMM support positions.

C5.4 Acquiring/Recording Data

Vibration measurements should be made during normal operations of the facility. Nearby equipment that will be operating when the CMM is expected to be in use should be running during the vibration testing. A written test log or voice channel on a data recorder should be maintained by the individual performing the test so that any abnormal events, such as temporary conditions resulting from construction, repair work, and the like, may be recorded during the test. A test should be repeated if an abnormal event occurs. Normal vehicular traffic should not be excluded. When the environmental conditions are satisfactory, the data should be recorded on tape, saved to memory, printed, or manually recorded.

C5.5 Comparing Vibration Data

After the data acquisition and analysis are complete, the data must be compared to the vibration acceptance criteria.

C5.5.1 Time History. For Time History criteria, this simply involves comparing the measured peak-to-peak vibration levels to the permissible level. The CMM supplier may provide horizontal, vertical, linear, and angular criteria. It is important to compare the acquired data to the criteria in the appropriate direction.

C5.5.2 Frequency Response Function. Comparison of Frequency Function criteria to frequency domain vibration data can be more effort than taking the data. If the criteria have the same level at all frequencies (straight line) or little changes in amplitude, it will be easy enough to draw the criteria over the printed vibration levels. If the criteria are not constant or uniform, it may be easier to compare data and criteria with various software programs. This involves digitizing the criteria, which in some cases requires entering levels at 1 Hz increments. The vibration data stored on the FFT analyzer must be down-loaded into a PC. This requires different steps depending on the analyzer manufacturer. Using a spreadsheet, math, graphing, or special program, the vibration data and criteria are combined into a single graph. Once the data is in a software format, it can be manipulated, graphed, and analyzed in a usable format.

C6 SUGGESTED CRITERIA ASSESSMENT

C6.1 Measure Vibration Below Criteria

If the vibration levels measured by the procedure above are within the supplier's criteria, no additional work is required. It is the sole responsibility of the supplier to maintain the performance of the CMM in order to meet specifications.

C6.2 Measured Vibration Above Criteria

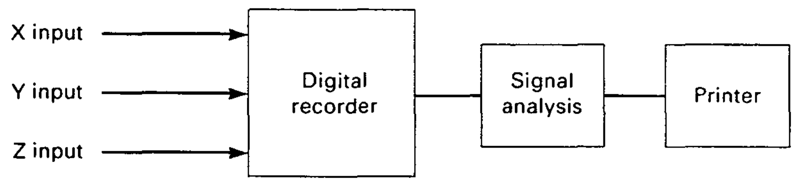
If, on the other hand, the vibration levels exceed the supplier's specifications, it is the responsibility of the user to isolate the vibration in order to conform to the specification or else accept a performance derating as described in ASME B89.4.1. Again, this Appendix does not provide information on how to reduce excessive vibration levels, but vibration isolation will reduce the levels. Before the vibration levels can be reduced, the source of the vibration must be determined. It may be easy to do this with the above equipment. Shock and vibration isolator suppliers specializing in low frequency vibration attenuation should be contacted if vibration isolation or a vibration survey is required.

C7 REPORT

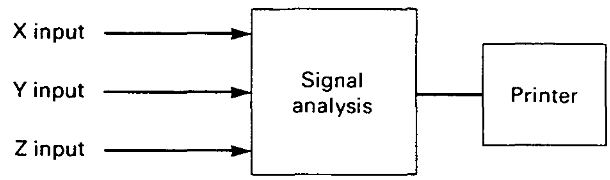
A report should be issued by the vibration specialist within approximately three (3) weeks. The report should include all backup information and analyzed data with a comparison to the CMM specification, and include the following as a minimum: Title, Dates (issued and when data was taken), Contract Number, Revision/Revision Date, Purpose or Scope, Instrumentation Used, Calibration Information, Description and Diagram of Test Setup, Procedure, Analysis, and Summary. It is important to note that the report should serve to archive the baseline vibration data for later review, if problems arise after CMM installation.

C8 FIELD INSTRUMENTATION DIAGRAM

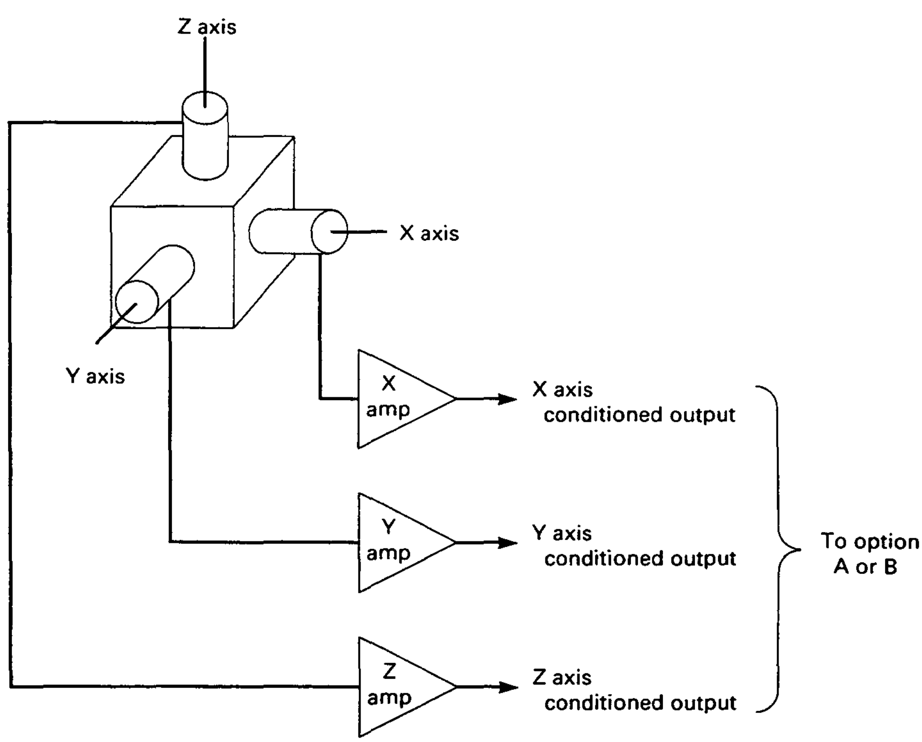
A diagram of typical instrumentation is shown in Fig. C-1.



Option A



Option B



Sensor Diagram

FIG. C-1 FIELD INSTRUMENTATION

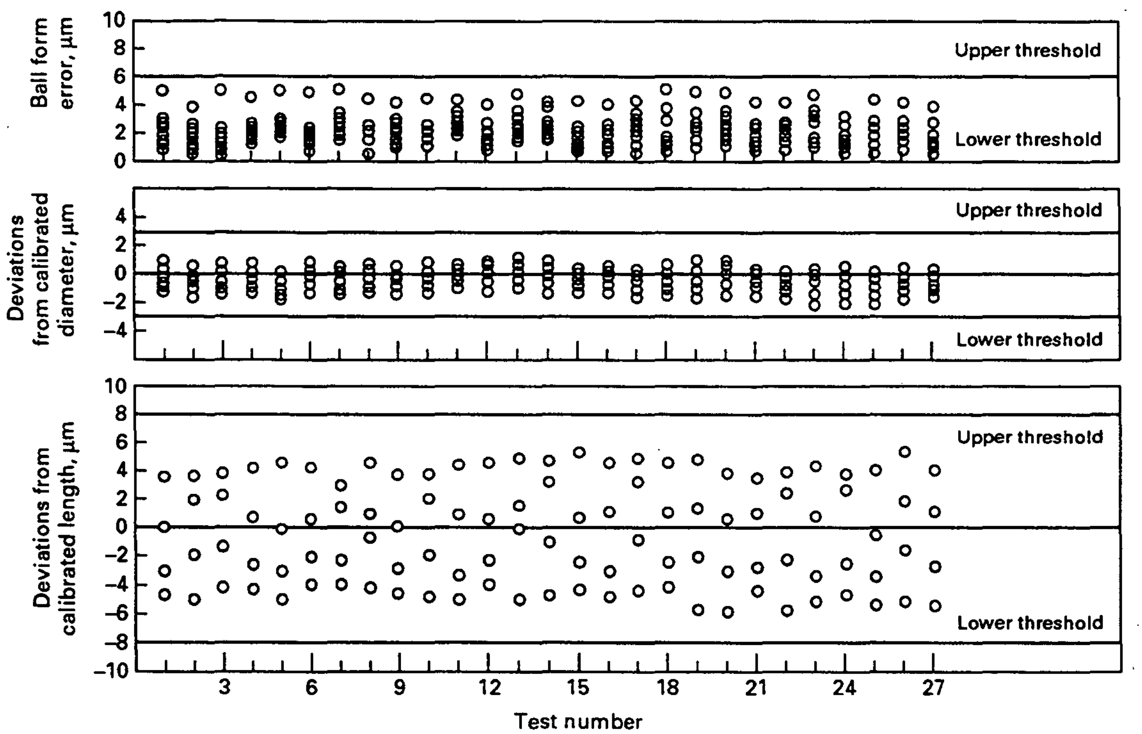


FIG. I5 SUMMARY PLOTS OF SEVERAL INTERIM TEST RESULTS

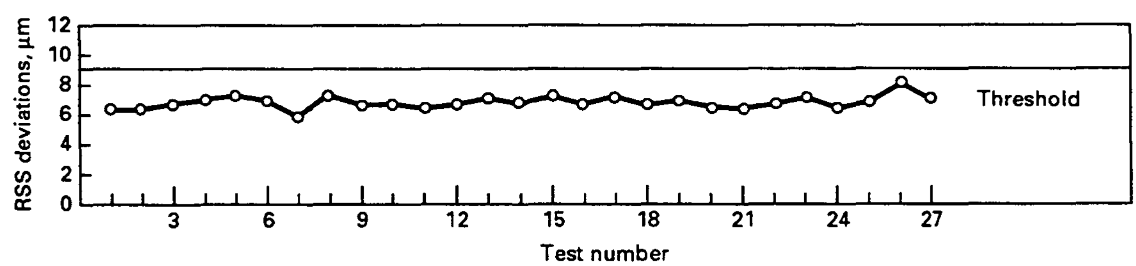


FIG. I6 SUMMARY PLOT OF COMBINED INTERIM TESTING RESULTS

ball location relative to others with different probe head orientations. The final body diagonal position checks for any defective probes present in the probe rack and the rack's probe changing ability. The first ball of the ball bar in this position is measured using the second probe obtained from the probe-changing rack, and the second ball of the ball bar is measured with the final (#3) probe from the probe rack. The form error and diameter, reported for each ball of the ball bar, test each of the two probes for probe lobing effects and stylus size calibration, respectively. (If additional probes are available, these could be checked by measuring each ball of the ball bar, in each ball bar position, with a different probe.)

Figure I5 shows one possible method of data analysis for the interim test. For each interim test, all four center-to-center length deviations, all eight ball diameters, and the eight measured sphere form errors are plotted. The test is passed if all these measurements are within the threshold value limits. Some users may prefer a single plot representing the test results (instead of the three shown in Figs. I4 and I5). Such a plot can easily be constructed, as shown in Fig. I6, by combining the largest length deviation, the largest diameter deviation, and one half the largest form deviation, in a root sum of squares (RSS) manner. (One-half the largest form deviation is used so each of the three contributions is appropriately weighted). This method has the advantage of displaying only a single graph but provides less information as to the sources of error. (If a CMM problem does develop, plots such as those in Fig. I5 could be constructed using data from the previous test results.)

There are many different methods a user can choose to establish testing thresholds. These include using the supplier's stated CMM performance values for the particular CMM under consideration, which might involve specifications from the ASME B89.4.1 or other appropriate national or international Standards. Other methods to determine the thresholds include examining the tightest tolerance of a feature found on the user's workpiece and reducing this by an appropriate ratio. To avoid false alarms, the threshold levels should exceed all variations arising from normal operations. This may include such factors as different operators and different thermal conditions, e.g., time of day or week.

I5 TESTING FREQUENCY

The frequency of interim testing is highly user-dependent. A CMM being operated three shifts a day with multiple operators in a harsh environment is likely to experience many more problems than the same machine being used one shift a day by a single operator in an excellent environment. The frequency of testing is also strongly affected by balancing the cost of interim testing against the consequences of accepting a bad workpiece or rejecting a good one. It may be useful to consider the interim testing interval as a percentage of total CMM operating hours. Some users with high value and/or safety critical workpieces may elect to perform daily tests; other users might test weekly or monthly. Additionally, interim testing should be conducted after any sort of significant event such as a CMM collision, replacement of a subsystem component, or the occurrence of abnormal temperature variations or gradients.

(a) I6 LARGE CMMS

CMMs with large work zones that are approximately cubical (1×1×1) should follow Appendix I with the following supplementary information. (For large CMMs, approximately cubical work zones can include all cases where the ratio of the work zone's longest to shortest axis is less than 2.) Appendix I recommends that a general purpose interim testing artifact should have its length at least 75% of the shortest axis of a CMM with a nearly cubical work zone. This condition may be difficult to fulfill with large CMMs, as the artifacts may become unwieldy, expensive, and difficult to calibrate. Furthermore, large interim testing artifacts may require special fixturing to avoid distortions caused by gravity or the probing force of the CMMs. Since these distortions often increase as the cube of the artifact's length, acceptably small distortions on short artifacts can rapidly become significant error sources as the length of the artifact increases. Consequently, fixturing which minimizes these effects is highly recommended. For example, when using a ball bar as the test artifact, a fixturing system such as the one shown in Fig. G4 is preferred to the free standing design shown in Fig. G1. Finally, thermal effects are especially important on large artifacts. The magnitude of these errors can be estimated by the Nominal Differential Expansion (NDE), and the uncertainty in the NDE (i.e., the UNDE, see para. 4.2).

The following recommendations provide alternative ways of overcoming the testing difficulties of large CMMs.

I6.1 Subwork Zones

Since some large CMMs use a significant fraction of their work zone for part mounting, a smaller work zone (or series of smaller work zones) might be used for the actual measurements (see *work zone* in glossary). In these cases, the testing artifact may comply with the recommendation of using the length equal to 75% of the shortest axis of the subwork zone. An example of such a situation would be a CMM which inspects physically large parts that need to fit into the work zone but with the actual measurement region on the part being a small subvolume of the part's physical size. Accordingly, a 0.9 m ball bar can easily be used to test a measurement work zone having a 1.2 m length side. Similarly, artifacts of length 1.5 m can be used to test measurement work zones having a shortest axis of up to 2 m. Artifacts greater than 1.5 m become increasingly problematic, a fact which represents the limit of practically implementing this approach.

I6.2 Artifact Staging

For very large CMMs, with the shortest work zone axis greater than 2 m, large physical artifacts may become impractical. In this situation a reasonably large artifact (e.g., 0.9 to 1.5 m) can be staged in the work zone. The staging should cover a distance of at least 75% of the shortest axis of the work zone. It is not recommended to stage the artifact more than three times since the artifact's length relative to the work zone size is small in this situation; hence, it loses sensitivity to angular errors (as explained in Appendix I) in addition to becoming very time consuming. Using this strategy with a 1.5 m artifact allows testing of a cubical work zone CMM with an axis of up to 6 m.

16.3 Testing With Optical Systems

For CMM work zones with a shortest axis of more than 2 m, the use of an optical displacement measuring system (e.g., a laser interferometer) may be desirable. If optical measurements are taken in nonstandard environmental conditions, then the wavelength corrections of para. 5.4.3.3 are recommended. Additionally, long beam paths may have spatial gradients present; this effect should be assessed and reduced (e.g., by air mixing with fans if necessary). The use of an optical system can employ the same procedure recommended for physical artifacts (i.e., the measurement of body diagonals) with at least one length being recorded for every 2 m of displacement traveled. For example, a CMM with a 4 m × 5 m × 6 m work zone could be tested along the body diagonal with at least 3 m of distance checked (75% of 4 m), and with at least one intermediate point recorded. Since for most optical systems the measurement time is a small fraction of the setup time, adding additional measurement points is advisable (e.g., in the above situation a measurement of the body diagonal lines of 7 m with the points spaced at 1 m intervals would be desirable). For large CMMs that are not vector driven (i.e., cannot operate all 3 axes simultaneously), it may be impossible to maintain the necessary optical alignment required by the laser interferometer. For these CMMs, an optical tracking system (e.g., laser tracker) can maintain the optical alignment as the body diagonals are traversed and may be used.

Care must be exercised to ensure that the optical measurement system has a sufficiently low uncertainty relative to the CMM under test. If it becomes necessary to move the beamsplitter/remote interferometer rather than the retroreflector when making length measurements, problems can arise if the beamsplitter is imperfectly made and bends the transmitted light slightly. Under these circumstances it is never possible to obtain good alignment of the beam with the direction of motion; it the laser beam exiting the beamsplitter is well aligned with the direction of motion, then the incoming beam will be misaligned and will walk across the face of the beamsplitter as the beamsplitter is translated. Thus a potential for both signal loss and misalignment errors exists when translating the beamsplitter. The problem is easily avoided by using a good quality optic than does not bend the transmitted light. Additionally, the correction for environmental effects on the wavelength of light over the measured distance should be considered a potential error source (see para. 5.4.3.3). Similarly, the use of optical coordinate systems (e.g., laser trackers) must have a sufficiently small system uncertainty relative to the CMM under test.

Since most optical systems used for interim testing do not involve the CMM probe or related subsystems, additional tests are needed to check these systems. A test sphere, calibrated for form and diameter, can be employed to check the CMM probe, indexable probe head, and CMM probe/stylus changing systems. For example, if all of the above subsystems are available, then a simple test would be to measure a calibrated sphere with a set of points taken using a combination of different probes/styli (accessed thorough probe/stylus changing) and different probe head index positions. This collection of points is (least squares) fitted to a sphere and the resulting form and diameter errors examined. The sphere's diameter error is a bidirectional length test and checks the probe's calibration for features of size (see para. 5.6), whereas the form error checks the probe lobing of the different probes (see para. 6.1), and the index positions relative to each other (see para. 6.2). Additionally, if the CMM has a part temperature compensation system, also known as an Automated Nominal Differential Expansion (ANDE) compensation system, this will not be tested during the optical measurement and should be checked independently; for example, by measuring a reasonably long calibrated artifact having nonzero expansion coefficient. During this measurement, the temperature of the artifact should be measured with the CMM part sensor and used for the ANDE correction. Deviations between the thermally compensated measured value and the calibrated value for the artifact length may indicate problems with the compensation system.

17 CMMS USED IN THE DUPLEX MODE (a)

For CMMs used in the duplex mode the procedures described in Appendix I can be used with at least some of the artifact measurements taken under the duplex condition. This is achieved by measuring opposite ends of the test artifact (ball bar, step gauge, gauge block, etc.) with different arms of the CMM. Similarly, if a ball plate (or hole plate) artifact is employed, then approximately half of the balls (holes) may be measured with each arm. If the CMM is rarely used in the duplex mode, then each arm may be interim tested independently and a few additional duplex measurements included. For very large CMMs used in the duplex mode, the use of a laser interferometer (or similar optical system) is recommended. In this case, the retroreflector is mounted in the ram of one arm and the interferometer is mounted in the ram of the second arm. (See the precautions above regarding testing with optical systems.) The distance between the two CMM arms is varied along a common direction determined by the laser beam path. If such an optical procedure is used, then the testing of the subsystems (e.g., probe head) is also needed, as described in Section I6.

(a) I8 HIGH ASPECT RATIO CMMS

CMMs having work zones with the ratio of the longest to shortest axis (the aspect ratio) greater than 2 may require modified testing procedures. For CMMs with aspect ratios of ≤ 3, and having body diagonals less than 4 m long, interim testing can be performed using an artifact at least one third the length of the body diagonal. For example, a CMM with axes of 0.5 m $\times$ 1 m $\times$ 1.5 m has a body diagonal 2 m long, thus a minimal length testing artifact would be 0.7 m. CMMs with aspect ratios greater than 3 are usually designed for a special purpose; for example, measuring the straightness of a long narrow part. In this case, a special purpose test designed around the measurement requirement may be appropriate. In the above example, the use of a straightness interferometer together with subsystem (e.g., probe) tests may be sufficient for the measurement application. In other situations the use of two ball bars may be sufficient to check the CMM. For example, one long bar could be oriented along some combination of body diagonals, long face diagonals, and the long axis of the CMM. A second shorter bar could be oriented along some combination of the short face diagonals and the short axes of the CMM.

I9 ROTARY TABLE CMMS (a)

CMMs having a rotary table can be tested by an abbreviated form of the 3D/alpha test described in para. 5.5.6. In cases where the measurement volume of interest is approximately that of the rotary table, the two ball setup of Fig. 33, with a minimum of four angular positions selected from Table 2, is sufficient to check the CMM. In situations where the measurement volume is substantially larger than that accessible to the rotary table, additional measurements using a method previously described (e.g., measuring a fixed length artifact) are recommended. Note that part loading effects can significantly affect the results of the 3D/alpha test.

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