Calibration of articulating arm coordinate measuring machines per ASME B89.4.22-2004

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Abstract. Solving issues in testing articulated arm coordinate measuring machines by bringing homogeneity to the process was the intention of the standard but it also had the consequence of being difficult to comply with in 100% totality. Accessibility to appropriate testing standards, whether financially or in their inherent stability can prove very difficult for a commercial calibration laboratory. Through hours of design & build and with deep testing resources, Trescal has created a platform from which AACMM with effective diameters up to 10.5 ft can be tested for touch measurement, and ISO17025 accredited, with full compliance to the B89 standard.

1.0 Introduction and Scope

For decades the standard do-all versatility of the coordinate measuring machine (CMM) was the only means for quality, metrology, and engineering departments alike to inspect complex pieces; although it left much desired in reach, adaptability, and portability. With the invention of the articulated arm coordinate measuring machine (AACMM) industry found itself a new workhorse, and as new and ever more complex production pieces continue to push the boundaries of existing quality & testing methods the AACMM has found its place in today's manufacturing world. Between its mobility and maneuverability it has quickly shown that it can suit nearly every need in production industries from engineering and troubleshooting to quality assurance.

This new inspection technology created the need to verify the proper working order of these new inspections tools. With no established international, or national committee, and with no accepted written standard for performance evaluation, each individual operator, department, or company was left to fend for themselves in determining test methods to prove out the degree of accuracy their AACMM operated within.

In 2004 the American Society of Mechanical Engineers (ASME) released document B89.4.22 and gave the necessary guidance to test performance operators had been missing. And even though it was not written as a stand-alone verification procedure it had the unintended side effect of giving commercial calibration laboratories a place in the market for performance evaluation. Assuming they could procure physical testing standards that complied with the written document. The standard focuses on the touch probe models only, and here only the performance evaluation will be discussed; environmental and vibration testing is left to operator implementation.

2.0 Description and Classification

An AACMM is a collection of rotating segments working around mostly perpendicular axes and are generally made up of three joints referred to as the shoulder, elbow & wrist. Each AACMM classification is made up of three numbers which represent the number of directional rotations each joint allows starting with the shoulder (base) and moving towards the wrist (probe). See Figure 1. This is further broken down by the degree of travel as well but is not discussed in detail here.

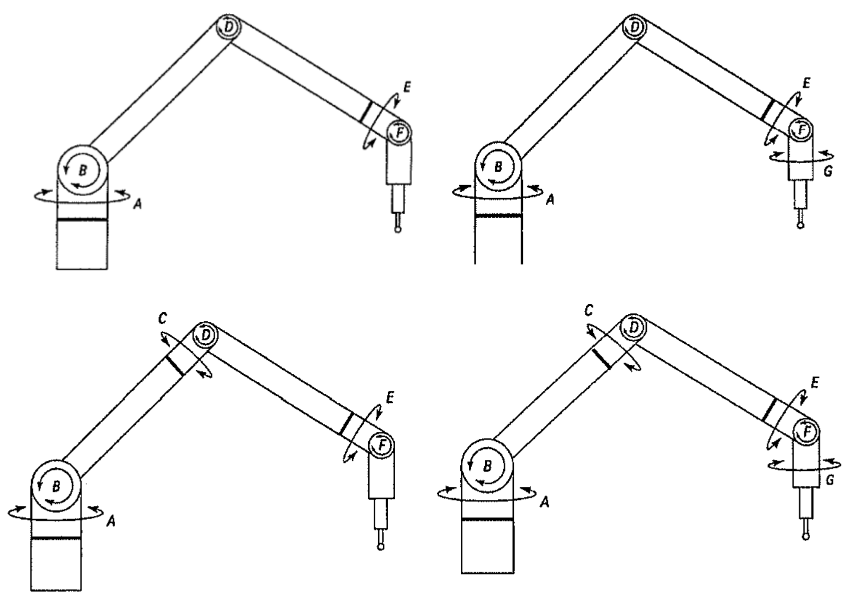

Figure 1. Example of arm classifications showing shoulder, elbow, and wrist joint articulation

3.0 Test Method

The test method is comprised of three tests: effective diameter performance test, single-point articulation performance test, and volumetric performance test. Testing an AACMM differs from a traditional CMM in that is has to evaluate a machine for a near infinite combination of locations and access directions where as on a traditional machine each reachable point is represented by a single coordinate on a three axis plane.

3.1 Test 1: Effective Diameter

The effective diameter performance test is completed at the approximate mid-reach of the AACMM and is done by probing nine points around specific areas of a mounted gage ball, like a standard CMM datum retrievable ball, with a known certified diameter. This is all done while minimizing arm articulation. The routine is completed three times and the maximum absolute deviation from the certified value of the ball is recorded as the test result. This test is intended to mimic the B89.4.1b bidirectional length test.

3.2 Test 2: Single-Point Articulation Performance Test (SPAT)

While the SPAT incorporates aspects of both a repeatability test and reproducibility test it is not either of them in result. The goal of the SPAT test is to prove out an ability to recreate a single fixed point within a measurement envelope of near infinite location and orientation combinations. This test is unique to the AACMM, as opposed to a traditional CMM, in that an AACMM "…uses a series of kinematic transformations to express the probe tip position, in one of any natural coordinate system, using the predetermined arm signet lengths and current rotary axis positions." [i]

The SPAT is completed using a chamfered hole, conical socket, or a trihedral socket. Any one is as suitable as the next so long as the hard probe tip and test seat, whether in practice or in theory, only make contact in three unchanging locations during the duration of the test.

SPAT testing is done at three different specified locations throughout the AACMM range, and is comprised of data for the single-point location of the standards seat when the arm is articulated to 10 different, but specific, orientations. Final results are considered the absolute maximum deviation of the data from the average of the same data, and also double the standard deviation of the point location.

3.3 Test 3: Volumetric Performance Test

Volumetric testing of an AACMM is done using the center-to-center distances of two different ball bars with verified, but different, overall lengths. This is different from the linear displacement accuracy testing done in B89.4.1b in that those tests do not have to explore the changes in orientation and plane that the AACMM is capable of producing. In all, the ball bars are placed into a total of 20 different positions throughout the arms range; four vertical positions, six horizontal positions, and ten 45° positions comprise the test setups. In each of these 20 positions five points per sphere are taken and the calculated centers of those points from end-to-end will be the resulting center-to-center reading.

The lengths of the ball bars needed are determined by the range of the AACMM. One bar is to be 25 to 38% of the AACMM diameter, and the other is to be 60 to 75%. When it comes to shorter bars for smaller units it is of little consequence to maintain the rigidness and manage the deflection during testing; thus ensuring the validity of the test results.

It becomes problematic however, when the range of the AACMM is large enough that the length of the ball bar starts to have implications as to the rigidity in its placement and against deflection while being probed. Whether it is from thermal changes, drooping during horizontal or angular testing, or gravitational compression of the bar during vertical mounting, any unknown deviation from certified length will render the results useless. Herein lies the difficulty of producing, or the expense in purchasing, standards to complete 100% compliant testing of AACMMs.

4.0 Ball Bar Standards

Stability and consistency are the two main concerns with the length of all ball bar standards. The task of maintaining the certified center-to-center distance throughout the test duration is, in part, dependent on the thermal expansion of the material it is made of, the rigidity of that same material, and also the way in which it is supported during testing. Accounting for and controlling these parameters are what make 100% compliance to the standard such a difficult task.

4.1 Thermal Effects

The two most common ball bar types used are either a solid cylinder or a round tube, and are most commonly made from either steel or invar. Invar being an alloy whose low coefficient of thermal expansion (CTE) makes it a great candidate for this type of use. In addition to its low CTE invar tubing is also light weight making it much easier to transport and stage during the testing procedure. Sufficient soak times for the standard bar inside the testing environment, as well as surface temperature probes will allow for temperature related compensation of the certified length but it is still advantageous to use a standard whose length is not changing drastically with changes in the ambient temperature.

4.2 Rigidity

Whether using a cylinder or a tube both materials would have suitable rigidity for smaller AACMM but as the required length of the bar increases with the size of the test unit the weight of the bar itself will become its enemy. Invar tubing will prove more suitable as bar lengths increase because of its light weight characteristic, creating a more forgiving scenario if the standard is ill supported.

4.3 Support

The main factor in limiting the deflection created when the probe force is applied to the ball bar sphere is the way in which it is supported. In contradiction to the characteristics of rigidity and portability, the invar tube is going to deflect more so than a solid steel bar. Supporting the bar as close to the ends as possible, without interrupting access to the spheres, is the best defense against ball bar spheres drooping.

5.0 Trescal Implementation

At the Milwaukee WI USA Trescal facility the group has been able to acquire or build standards which have allowed 100% compliance with the B89 procedure. And with access to length measuring standards which allow them to verify these long, in the case of the ball bar, standards in their own laboratory they are able to maintain them with lower financial burden and less down time than their industry counterparts.

5.1 Datum Retrieval Ball

A standard CMM datum retrieval, Figure 2, ball is used for the Effective Diameter procedure; this is the most basic and straight forward of the testing and standards.

Figure 2. Datum retrieval ball for Effective Diameter test

5.2 Single Point Articulation Test

For the SPAT routine three individual 3-ball trihedral sockets of varying sizes were assembled to account for the different probe tips sizes available. Figure 3. The 3-ball trihedral socket was chosen over the other options because it is the only one that will produce a nearly ideal 3-point kinematic coupling/restraint.

Figure 3. Set of three 3-ball trihedral sockets for SPAT

5.3 Ball Bar

The ball bar, see figure 4 & 5, requirements in the B89 were the most difficult to comply with while developing appropriate physical test standards. As an alternative to the more traditional steel or Invar bars discussed earlier the group opted for carbon fiber reinforced polymer (CFRP or carbon fiber) tubing. This option provided three distinct advantages as compared to the other two more prevalent choices.

5.3.1 Rigidity

First, the strength to weight ratio is far superior resulting in a much stiffer test bar. Having higher tensile strength and specific strength (strength divided by density) the carbon fiber tubing provides the necessary rigidity without compromising the ability to easily transport and position the bars for testing. See Table 1.

Table 1

	CTE ppm/°C	Specific Strength kN*m/kg	Tensile Strength Mpa	Density g/cm^3
Invar	1.2	101.3	810	8
Stainless Steel	11	63.1	505	8
CFRP	-0.8	2457	4300	1.75

5.3.2 Corrosion Resistance

Second, the carbon fiber tubes also provide a higher level of resistance to corrosion. While this may seem a minor point of advantage because the individual care and cleaning of the standards can prolong useful life, these bars are still not without contamination. Because many customers are requesting, or requiring, that the AACMM testing be done at their facility it is difficult, or even impossible, to control for environmental conditions and contaminants; namely water vapor as the most detrimental to the life of the standards. The carbon fiber standards employed by Trescal have a sealed wrap around the length of them which is water resistant and means a simple wipe down before storage and use of a desiccant during storage will suffice to maintain the integrity of bars.

5.3.3 Thermal Expansion

Third, one of the main advantages of the carbon fiber tubing is its low CTE. Most carbon fiber composites have a CTE of approximately zero and studies have proven that expansion can even be negatively correlated with temperature. See Table 1. One drawback to this material though, because of differences in manufacturing processes and component makeup among others, it can be difficult to know the exact CTE of each particular bar. It is strongly suggested that carbon fiber materials used for the production of ball bar standards come from a supplier that has done independent testing on each lot of tubing to determine its true CTE for use during AACMM testing.

Figure 4. Ball bar in horizontal position for test

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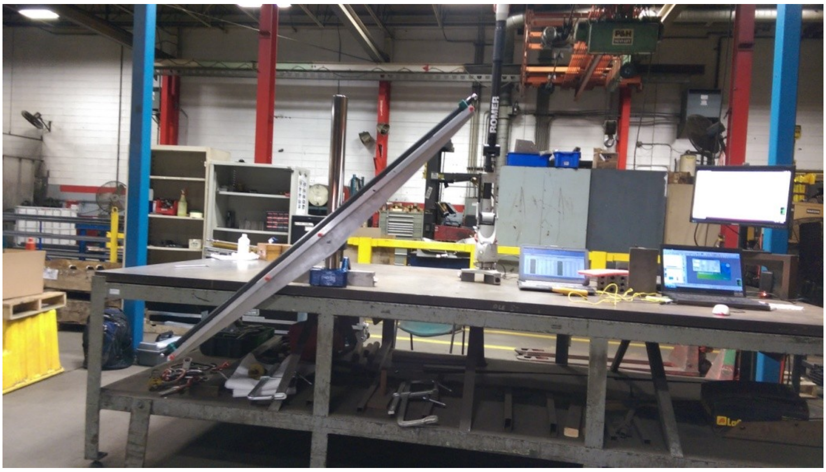

Figure 4. Ball bar in 45° position for test

References

ASME B89.4.22-2004; date of issuance August 12, 2005; reaffirmed 2014

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www.nickel-alloys.net/invar_nickel_iron_alloy.html

https://en.wikipedia.org/wiki/Thermal_expansion

https://en.wikipedia.org/wiki/Invar

https://en.wikipedia.org/wiki/Specific_strength

[i] ASME B89.4.22 paragraph 5.3.1