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Standard Practice for Verification of Multi-Axis Force Measuring Platforms[1]

This standard is issued under the fixed designation F3109; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This standard recommends practices for performance verification of multi-axis force platforms commonly used for measuring ground reaction forces during gait, balance, and other activities.

1.1.1 This standard provides a method to quantify the relationship between applied input force and force platform output signals across the manufacturer's defined spatial working surface and specified force operating range.

1.1.2 This standard provides definitions of the critical parameters necessary to quantify the behavior of multi-axis force measuring platforms and the methods to measure the parameters.

1.1.3 This standard presents methods for the quantification of spatially distributed errors and absolute measuring performance of the force platform at discrete spatial intervals and discrete force levels on the working surface of the platform.

1.1.4 This standard further defines certain important derived parameters, notably COP (center of pressure) and methods to quantify and report the measuring performance of such derived parameters at spatial intervals and force levels across the working range of the force platform.

1.1.5 This standard defines the requirements for a report suitable to characterize the force platform's performance and provide traceable documentation to be distributed by the manufacturer or calibration facility to the users of such platforms.

1.1.6 Dynamic characteristics and applications where the force platform is incorporated in other equipment, such as instrumented treadmills and stairs, are beyond the scope of this standard.

1.1.7 This standard is written for purposes of multi-axis force platform verification. However, the methods and procedures are applicable to calibration of force platforms by manufacturers.

1.2 The values stated in SI units are to be regarded as the standard. Other metric and inch-pound values are regarded as equivalent when required.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[1] This practice is under the jurisdiction of ASTM Committee F04 on Medical and Surgical Materials and Devices and is the direct responsibility of Subcommittee F04.15 on Material Test Methods.

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***A Summary of Changes section appears at the end of this standard**

2. Referenced Documents

2.1 *ASTM Standards:*[2]
E4 Practices for Force Calibration and Verification of Testing Machines
E74 Practices for Calibration and Verification for Force-Measuring Instruments

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *center of pressure (COP), n*—the spatial point on the surface of a force platform at which a single equivalent force has the same static effect as the sum of the distributed forces and the distributed moments acting on the system.

3.1.2 *COP error, n*—difference between the COP x-y position reported by the force platform (or calculated from the force platform outputs) and the actual x-y location of the applied Fz verification force.

3.1.3 *crosstalk or crosstalk error, n*—response of an output channel corresponding to an unloaded axis when a force or a moment is applied to a different axis.

3.1.4 *force platform origin, n*—the position on the force platform, specified by the manufacturer, where x, y, and z = 0. The origin serves as a reference position for the COP x and COP y locations, locations for uniaxial forces applied during verification, and for calculating output moments due to input forces. The origin may be at a different x-y-z position from the force platform's geometric center. The force platform origin is sometimes called the electro-mechanical origin.

3.1.5 *Fx and Fy, n*—forces orthogonal to Fz, assigned per Fig. 1 which follows the right-hand coordinate system ("right-hand rule") convention for directionality.

3.1.6 *Fz, n*—force that is orthogonal to the working surface of the platform. Fz and z distances are positive going downward when the force platform is mounted on the floor.

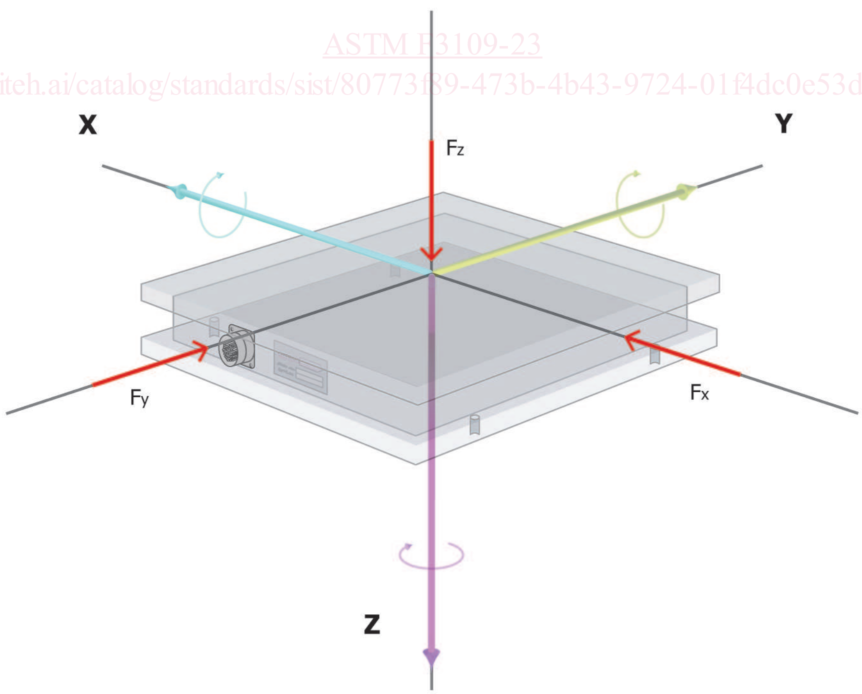

FIG. 1 Force Platform Orthogonal Coordinate Conventions

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.7 *moment, n*—a vector equal to the cross product of a position vector and a force vector. Given a position vector d = {x, y, z} that indicates a point, relative to a given origin, which is on the line of action of a force F = {Fx, Fy, Fz} then the components of the moment vector M = {Mx, My, Mz} relative to the origin are:

$$Mx = y \cdot Fz - z \cdot Fy$$
$$My = z \cdot Fx - x \cdot Fz$$
$$Mz = x \cdot Fy - y \cdot Fx$$

If the point indicated by d lies on the surface of the force platform, then that point is also the COP of F.

3.1.8 *Mx, My, and Mz, n*—moments around the x, y, and z axes, respectively, following the right-hand coordinate system convention for directionality.

3.1.9 *multi-axis force plate, n*—synonym for multi-axis force platform.

3.1.10 *multi-axis force platform, n*—a transducer with a flat measuring surface capable of measuring three orthogonal force components, three orthogonal moment components, and directly or indirectly measuring the center of pressure x-y position.

3.1.11 *serialized calibration values, n*—calibration values that apply to a specific force platform with a specific serial number. The calibration values may be used in the force platform, in an amplifier, or in a computer that makes up a calibrated force-measuring platform system.

3.1.12 *traceable force standard, n*—a force transducer or dead weight that is traceable to national standards and is more accurate than the instrumentation that is being verified. In this method, if dead weights are used then corrections for gravity shall be applied per Practice E4 and their center of mass shall be spatially balanced around the axis of loading such that forces applied to the force platform are applied at a known location.

3.1.13 *uniaxial force, n*—force that is only in the direction of the intended axis without imparting forces in the two orthogonal axes. For example, applying Fz uniaxially shall not cause Fx or Fy forces greater than 10 % of the Fz to Fx or Fz to Fy crosstalk specified by the force platform's manufacturer.

3.1.14 *working surface, n*—the flat area of the platform where ground reaction forces are measured while patients or subjects perform activities such as walking, standing, running, and other activities. In most applications the working surface is oriented horizontally and is the top surface of the force platform.

3.1.15 *x-y-z position, n*—the position where the force verification vector is applied with respect to the force platform's origin.

4. Summary of Practice

4.1 This standard practice has three sections:

4.1.1 Uniaxial test forces are applied to the force platform using traceable force standards. The forces are applied for at least five force values over a range of positions spanning the manufacturer's specified working surface dimensions. The force platform's outputs are recorded at each force and position. To ensure adequate quality of measurement at all locations of force application, the spatial errors should be sampled by test forces at appropriately small spatial intervals. In this standard, a grid pattern to ensure proper spatial characterization of errors is presented (see Fig. 2).

4.1.2 The recorded force platform outputs are analyzed at all forces and positions to compare the force platform's Fx, Fy, Fz, Mx, My, Mz, COP x, and COP y measuring errors and crosstalk performance with the manufacturer's specifications. These comparisons determine whether the force platform is successfully verified.

4.1.3 A report which includes graphical presentation of the results shall be prepared.

5. Significance and Use

5.1 Multi-axis force measuring platforms are used to measure the ground reaction forces produced at the interface between a subject's foot or shoe and the supporting ground surface. These platforms are used in various settings ranging from research

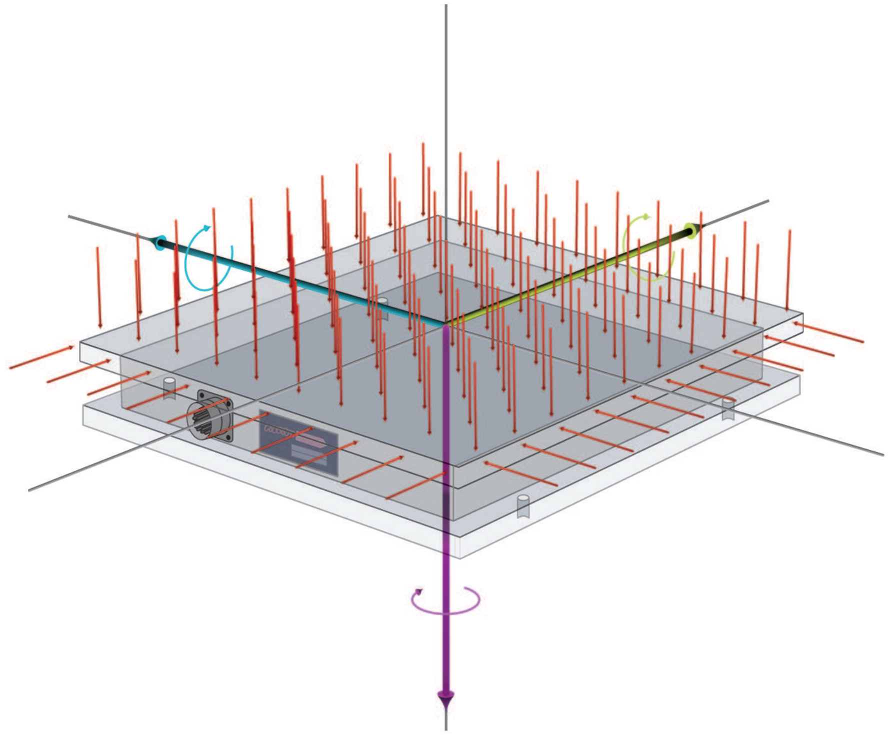

FIG. 2 Illustration of Spatial Grid Pattern Used to Apply Forces for Force Platform Verification

laboratories to healthcare facilities. The use of force platforms has become particularly important in gait analysis where clinical evaluations have become a billable clinical service.

5.2 Of particular importance is the application of force platforms in the treatment of cerebral palsy (CP) (**1, 2**).[3] An estimated 8000 to 10 000 infants born each year will develop CP (**3**) while today's affected population is over 764 000 patients (**4**). Quantitative gait analysis, using force platforms and motion capture systems, provides a valuable tool in evaluating the pathomechanics of children with CP. This type of mechanical evaluation provides a quantitative basis for treating neuromuscular conditions. In other words, surgical decisions are in part guided by information gained from the use of force platform measurements (**5, 6**).

5.3 Another application is treatment of spina bifida. According to the Gait and Clinical Movement Analysis Society (GCMAS) (**7**), an instrumented gait analysis is the standard of expert care for children with gait abnormalities secondary to spina bifida. The main objective of diagnostic gait analysis is to define the pathological consequences of neural tube defects as they relate to gait. The use of instrumented gait analysis allows physicians to determine which surgical or non-surgical interventions would provide the best outcome.

5.4 More recently, force platforms have been used for pre- and post-surgical evaluation of TKA (total knee arthroplasty) and THA (total hip arthroplasty) patients. Such data provides an objective measure of the mechanical outcome of the surgical procedure.

5.5 In addition to the clinical applications there are numerous medical and human performance research activities which rely on accurate measurement of ground reaction forces by using multi-axis force platform measurement instruments.

5.6 As a standards organization, ASTM has historically provided excellent standards for the calibration of force transducers and force-measuring instrumentation. Force platforms, however, are different from force transducers. Force platforms typically provide a large active working surface, whereas force transducers provide more or less a single point of interaction with the load-applying environment. Moreover, force platforms typically provide six-axis measurements and are expected to be used in environments causing multi-axial loading.

[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

6. Apparatus

6.1 The apparatus shall have the following attributes:

6.1.1 The apparatus shall apply all Fx, Fy, and Fz forces using a traceable force standard. See Practice E74–13a, Sections 5 and 6.

6.1.2 The apparatus shall apply all forces using a single, flat contact pad to concentrate force distribution as might be encountered during heel strike. The shape and dimensions of the contact pad shall be specified in the report.

6.1.3 The apparatus shall apply all forces uniaxially in an axis that is coincident with the axis of the force platform being verified. For example, Fz shall be applied perpendicular to the force platform's working surface without causing Fx or Fy forces greater than 10 % of the Fz to Fx or Fz to Fy crosstalk specified by the force platform's manufacturer.

6.1.4 The apparatus shall measure and report the position of the applied forces with an accuracy of ±0.1 mm.

6.1.5 The apparatus shall be located in an environment with sufficient stability that verification results are unaffected by environmental variations.

6.1.6 The apparatus shall be at a steady-state operating condition before verification begins so that the equipment itself does not introduce any errors.

6.1.7 Care shall be taken to minimize transient vibrations when verification is being performed.

6.2 Users of this standard shall ensure that the force platform's serialized calibration information provided by the manufacturer is in effect. For example, if the force platform requires the end user to apply calibration files from a computer or to use the force platform with an amplifier as a matched pair, the user of this standard shall ensure that the force platform (or force platform and amplifier combination) is using the correct force platform's serialized calibration values before beginning verification.

7. Verification Procedure

7.1 Before proceeding with the verification, a warm-up period with all electronics powered may be necessary to achieve stable temperatures and outputs. Reviewing the force platform manufacturer's recommendations regarding a warm-up period is recommended.

7.2 Before any forces are applied to the force platform, ensure that the traceable force standard is not touching the force platform. Then, zero the outputs of all six force platform outputs and, if used, the traceable force transducer. This step may be repeated at each position.

7.3 Note that all x-y-z positions in the verification procedure are relative to the force platform's origin as defined in 3.1.

7.4 Apply Fz to the working surface of the force platform.

7.4.1 Apply Fz at points making up an evenly spaced grid spanning the force platform's working surface. Grid count should be 100 or more grid points, and the x and y grid spacing should be approximately 25 mm (1 in. in U.S. customary units) or less. Use of fewer positions or larger spacing increments shall be noted and justified in the report. The spacing between measurements shall be sufficiently close so that the uncertainty of the force platform's outputs due to interpolation between positions is less than the force platform's specified accuracy. The x and y positions where Fz is applied shall be measured with an accuracy of ±0.1 mm.

7.4.2 At each x-y position, apply five or more different Fz forces. Begin with a minimum force that is no less than 5 % and no greater than 10 % of the force platform's Fz full scale. Monotonically increase the applied force and end at the force platform manufacturer's specified Fz full-scale capacity. For each applied Fz and x-y position, record the force applied by the force standard (either the output of the standard force transducer cell or the force applied by the standard weights); the x and y positions of Fz; and the force platform's outputs Fx, Fy, Fz, Mx, My, Mz, and, if provided by the force platform, COP x and COP y. The COP is frequently not a direct output of the force platform but is calculated from the force and moment outputs of the platform. Each recorded value at each Fz and x-y position shall consist of an average of several readings. The readings for each recorded value shall be of sufficient quantity that variability due to noise is characterized. Additionally, the readings shall be sufficiently stable that the variability of the readings at each Fz and x-y position is less than the performance attribute being verified. For example, if the accuracy of Fz is being verified at 1000 N, and the platform manufacturer specifies an accuracy of ±0.2 % of full scale and full scale is rated at 4448 N, then the readings shall be more stable than ±8.9 N.

7.5 Apply Fx forces to a surface of the force platform that is ~~perpendicular~~parallel to the y-z plane.

7.5.1 Apply Fx at evenly spaced positions in the positive direction. There should be ten or more positions. Spacing should be no greater than approximately 25 mm (1 in. in U.S. customary units). Use of fewer positions or larger spacing increments shall be noted and justified in the report. The spacing between measurements shall be sufficiently close so that the uncertainty of the force platform's outputs due to interpolation between positions is less than the force platform's accuracy. The y position where Fx is applied shall be measured with an accuracy of ±0.1 mm. Apply Fx at a known z position.

7.5.2 At each y-z position, apply five or more different Fx forces. Begin with a minimum force that is no less than 5 % and no greater than 10 % of the force platform's Fx full scale. Monotonically increase the applied force and end at the force platform manufacturer's specified Fx full-scale capacity. At each Fx and y-z position record the force platform's outputs, the force applied by the force standard, and y-z positions per section 7.4.2 (recording y-z positions of Fx instead of x-y positions of Fz).

7.6 Apply Fy forces in the positive direction to a surface of the force platform that is ~~perpendicular~~parallel to the x-z plane. Record outputs and applied forces per 7.5 (applying Fy at x-z positions, using the force platform's Fy full-scale capacity, and recording x-z positions of Fy).

7.7 Verify the force platform's performance.

7.7.1 Create a table with all applied forces, their x-y-z locations, and all outputs recorded from the force platform (Fx, Fy, Fz, Mx, My, Mz, and, if available, COP x and COP y).

7.7.2 Calculate Fx, Fy, Fz, Mx, My, and Mz measuring errors.

7.7.2.1 Calculate the Mx, My, and Mz values for each applied force and location using the force applied by the force standard and the distance of the applied force from the force platform's x-y-z origin. Mx and My are calculated using Fz values and x-y locations. Mz is calculated using either Fx or Fy values and the corresponding y or x locations.

7.7.2.2 Calculate the force platform's force and moment measuring errors for Fx, Fy, Fz, Mx, My, and Mz at each applied force value and location. Calculate measuring errors using one of the following methods. The method used should be stated in the report.

(1) Calculate the error as the difference between the applied force (or moment) and the force platform's output for that axis.

(2) Calculate the error as a percent of full scale by dividing the difference between the applied force (or moment) and the force platform's output value for that axis by the force platform's full scale for that axis. Express the result as a percentage.

(3) Calculate the error as a percent of the applied force (or moment) by dividing the difference between the applied force (or moment) and the force platform's output value for that axis by the applied force (or moment). Express the result as a percentage.

7.7.3 Calculate Fx, Fy, Fz, Mx, My, and Mz crosstalk values. At each applied force and position, calculate crosstalk by dividing the force platform's output value for each axis that does not have a force or moment applied to it ("Recorded Crosstalk Axis" in Table 1) by the applied force. Express the result as a percentage. Include the units of measurement when the recorded crosstalk axis is Mx, My, or Mz. For example, include "N-m/N" when Mz is the recorded axis while Fz is the applied force.

7.7.4 Calculate the COP x and COP y position errors. For the selected Fz value, at each x-y position where Fz was applied, calculate the difference between the x position where Fz was applied and the COP x position recorded from the force platform (or calculated from the force platform's outputs). Perform the same calculations at all x-y positions for COP y.

7.7.4.1 For purposes of this verification standard, where Fz is applied uniaxially and therefore Fx and Fy = 0, COP x and COP y may be calculated as follows:

(1) COP x = –My / Fz

(2) COP y = Mx / Fz

7.8 Compare the force and moment-measuring errors (Fx, Fy, Fz, Mx, My, Mz), COP x, and COP y position errors, and crosstalk values to the corresponding specifications from the force platform manufacturer. Perform the comparison for all applied forces and

TABLE 1 Crosstalk Axes and Values for Each Applied Force

Applied Force	Recorded Crosstalk Axis	Result
Fx	Fy	Series of crosstalk values at all y positions for Fx
	Fz	Series of crosstalk values at all y positions for Fx
	Mx	Series of crosstalk values at all y positions for Fx
Fy	Fx	Series of crosstalk values at all x positions for Fy
	Fz	Series of crosstalk values at all x positions for Fy
	My	Series of crosstalk values at all x positions for Fy
Fz	Fx	Series of crosstalk values at all x-y positions for Fz
	Fy	Series of crosstalk values at all x-y positions for Fz
	Mz	Series of crosstalk values at all x-y positions for Fz

positions. An example of such a comparison for Fz accuracy at one x-y-z position is shown in Appendix X1. If all measuring errors and crosstalk values are within the manufacturer's specifications at all applied verification forces and locations, then the force platform is considered verified.

8. Report

8.1 Report the following:

8.1.1 Date of verification test.

8.1.2 Date of report approval.

8.1.3 Organization or facility name and address where the verification was performed.

8.1.4 Temperature and humidity in the environment of the verification.

8.1.5 Manufacturer, model number, and serial number of the force platform (and amplifier, if required) that was verified.

8.1.6 Optionally, the calibration matrix of the force platform that was verified.

8.1.7 Type of force standards used and traceability information.

8.1.8 Shape and dimensions of the force application contact area.

8.1.9 Statement that the verification has been performed in accordance with ASTM Practice F3109–year of approval.

8.1.10 Whether the force platform passed verification.

8.1.11 Names of people who performed the verification.

8.1.12 Name and signature of the person responsible for ensuring the correct application of this standard and the verification result.

8.1.13 Method used for calculating force and moment measuring errors.

8.1.14 Force-measuring errors of Fx, Fy, Fz, Mx, My, and Mz at all x-y positions. Force-measuring errors are reported at a force (or moment) that is representative of the intended force platform's application. 890 N is suggested for human gait studies. Force-measuring errors shall be reported as a percentage of applied force or as the difference between the recorded force (or moment) and the applied force (or moment) in force (or moment) units. Present the results as three-dimensional surface plots. See Annex A1 for examples.