Designation: E1830 – 15

Standard Test Methods for Determining Mechanical Integrity of Photovoltaic Modules [1]

1. Scope

1.1 These test methods cover procedures for determining the ability of photovoltaic modules to withstand the mechanical loads, stresses and deflections used to simulate, on an accelerated basis, high wind conditions, heavy snow and ice accumulation, and non-planar installation effects.

1.1.1 A static load test to 2400 Pa is used to simulate wind loads on both module surfaces.

1.1.2 A static load test to 5400 Pa is used to simulate heavy snow and ice accumulation on the module front surface.

1.1.3 A twist test is used to simulate the non-planar mounting of a photovoltaic module by subjecting it to a twist angle of 1.2°.

1.1.4 A cyclic load test of 10 000 cycles duration and peak loading to 1440 Pa is used to simulate dynamic wind or other flexural loading. Such loading might occur during shipment or after installation at a particular location.

1.2 These test methods define photovoltaic test specimens and mounting methods, and specify parameters that must be recorded and reported.

1.3 Any individual mechanical test may be performed singly, or may be combined into a test sequence with other mechanical or nonmechanical tests, or both. Certain preconditioning test methods such as annealing or light soaking may also be necessary or desirable as a part of such a sequence. However, the determination of such test sequencing and preconditioning is beyond the scope of these test methods.

1.4 These test methods do not establish pass or fail levels. The determination of acceptable or unacceptable results is beyond the scope of these test methods.

1.5 These test methods do not apply to concentrator modules.

1.6 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.7 The following precautionary caveat pertains only to the hazards portion, Section 6, and the warning statements, 7.5.3.2 and 7.6.3.2, of these test methods. *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E772 Terminology of Solar Energy Conversion

E1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells

E1462 Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules

E1799 Practice for Visual Inspections of Photovoltaic Modules

3. Terminology

3.1 *Definitions*—Definitions of terms used in these test methods may be found in Terminology E772.

4. Significance and Use

4.1 The useful life of photovoltaic modules may depend on their ability to withstand periodic exposure to high wind forces, cyclic loads induced by specific site conditions or shipment methods, high loads caused by accumulated snow and ice on the module surface, and twisting deflections caused by mounting to non-planar surfaces or structures. The effects on the module may be physical or electrical, or both. Most importantly, the effects may compromise the safety of the module, particularly in high voltage applications, or where the public may be exposed to broken glass or other debris.

4.2 These test methods describe procedures for mounting the test specimen, conducting the prescribed mechanical tests, and reporting the effects of the testing.

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[1] These test methods are under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and are the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.

Current edition approved Feb. 1, 2015. Published March 2015. Originally approved in 1996. Last previous edition approved in 2009 as E1830 - 04. DOI: 10.1520/E1830-15.

[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.

4.2.1 The mounting and fastening method shall comply with the manufacturer's recommendations as closely as possible. If slots or multiple mounting holes are provided on the module frame for optional mounting point capability, the worst-case mounting positions shall be selected in order to subject the module to the maximum stresses.

4.2.2 If an unframed module is being tested, the module shall be mounted in strict accordance with the manufacturer's instructions using the recommended attachment clips, brackets, fasteners or other hardware, and tightened to the specified torque.

4.2.3 The test specimen is mounted on a test base in a planar manner (unless specified otherwise), simulating a field mounting arrangement in order to ensure that modules are tested in a configuration that is representative of their use in the field.

4.2.4 During the twist test, the module is mounted in a manner simulating a non-planar field mounting where one of the fastening points is displaced to create an intentional twist of 1.2°.

4.3 Data obtained during testing may be used to evaluate and compare the effects of the simulated environments on the test specimens. These test methods require analysis of both visible effects and electrical performance effects.

4.3.1 Effects on modules may vary from no changes to significant changes. Some physical changes in the module may be visible even though there are no apparent electrical performance changes. Conversely, electrical performance changes may occur with no visible change in the module.

4.3.2 All conditions of measurement, effects of the test exposure, and any deviations from these test methods must be described in the report so that an assessment of their significance can be made.

4.4 If these test methods are being performed as part of a combined sequence with other mechanical or nonmechanical tests, the results of the final electrical test (7.2) and visual inspection (7.3) from one test may be used as the initial electrical test and visual inspection for the next test; duplication of these tests is unnecessary unless so specified.

4.5 Some module designs may not use any external metallic components and thus lack a ground point designation by the module manufacturer. In these cases, the ground path continuity test is not applicable.

5. Apparatus

5.1 In addition to the apparatus required for Test Methods E1036 and E1462, the following apparatus is required.

5.2 *Open Circuit Fault Detection*—Instrumentation for monitoring the module under test for open circuit conditions during the mechanical integrity tests. An acceptable apparatus is described in Annex A1.

5.3 *Static Load Test Apparatus:*

5.3.1 *Test Base*—A rigid test base shall be provided that enables the module to be mounted front-side up or front-side down in accordance with the requirements of 4.2.1 – 4.2.3. The test base shall enable the module to deflect freely during load application to preclude any inadvertent interference or limiting of the normal deflections.

5.3.2 *Load Measurement Equipment*—Means shall be provided for measuring the applied load to within the prescribed tolerances.

5.3.3 *Loads*—Suitable masses or means of applying pressure shall be provided that enable the load to be applied in a gradual, uniform manner. Some examples of loads that can be used are:

5.3.3.1 Stacks of paper or small canvas or plastic bags filled with several kilograms of sand, loose stones, or lead shot in a sufficient quantity to meet the total load requirement,

5.3.3.2 A water bag that can be progressively filled to increase the load,

5.3.3.3 A pneumatic bag that can be inflated to a controlled pressure and that is located between the module and a fixed surface (see 5.5, Cyclic Load Test Apparatus),

5.3.3.4 Loose sand can be used provided that a perimeter retaining skirt of cardboard or thin plywood, for example, is employed around the module perimeter to retain the sand and maintain load uniformity to the module edges, or

5.3.3.5 Bricks or cement blocks may be used, but a pad should first be placed on the module to prevent scratch or particle damage. With such rigid load elements, care should be exercised to minimize load concentration points.

5.3.3.6 If the applied load is comprised of discrete load elements such as bags, bricks, or blocks, the individual units shall weigh within 5 % of one another to ensure the application of a uniform load on the module.

5.3.3.7 The applied load may be measured by pre-weighing the load elements, or the load may be measured in situ during the test by the use of load scales incorporated into the test apparatus. If a pneumatic bag is used, the load can be measured with a pressure gage because the load is provided by pneumatic pressure.

5.4 *Twist Test Apparatus:*

5.4.1 A rigid test fixture shall be provided that allows the module to be installed in a flat, planar configuration, and that permits the displacement of one of the attachment points such that a twist is induced in the module (see Fig. 1). The test fixture must meet the requirements of 4.2.1 – 4.2.4.

5.4.2 Acceptable test fixtures capable of meeting this requirement include a simple table and shim arrangement, or a more complicated rack structure with a special screw adjustment for imposing the twist-inducing displacement.

5.5 *Cyclic Load Test Apparatus*—Several schemes are available for conducting the cyclic load test. Whichever scheme is selected must adhere to the requirements of 4.2.1 – 4.2.3. Schemes that have been found acceptable are:

5.5.1 *Air Bag Scheme*—With this scheme, pressure is applied by inflatable air bags. The module is sandwiched between two inflatable air bags which in turn are sandwiched between rigid or semirigid backing plates. By pressurizing the bag on one side of the module while the bag on the opposite side is vented to the atmosphere, a uniform pressure load equal to the pressure in the bag is applied to the module. By reversing which bag is pressurized and which is vented, an alternating or cyclic load is applied.

5.5.1.1 The distance between the module and the backing plates must be carefully adjusted to ensure that the pressure

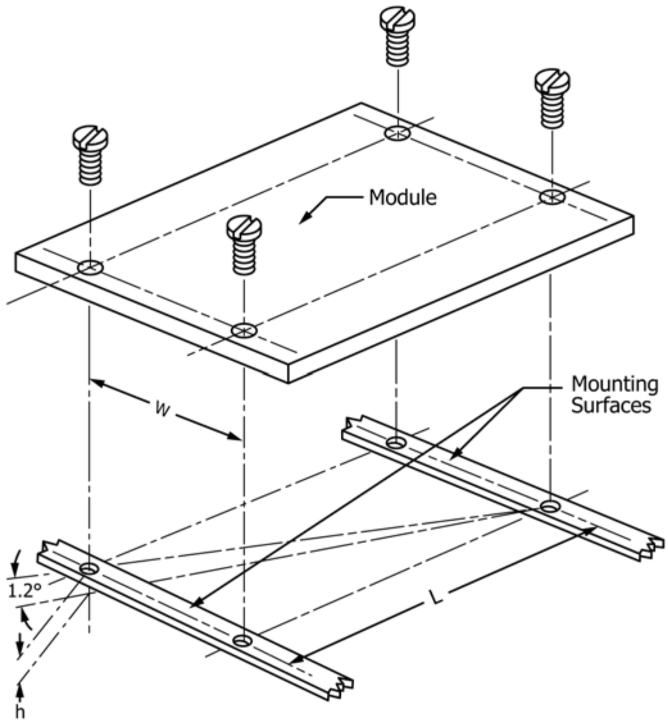

FIG. 1 Deflection to be Applied by the Twist Test Fixture

within the air bag is applied to the panel and not reacted by membrane tensile forces developed in the bag material. The air bag will not develop undesirable tensile stresses when pressurized appreciably less than its normal inflated thickness.

5.5.1.2 The backing plates should not be so close to the module that it can interfere with the deformation or deflection of the module when the bag on the other side of the module is inflated.

5.5.2 *Piston and Pillow Scheme*—With this scheme, the module is sandwiched between two rigid or semirigid platens, each driven by a pneumatic piston as the means for applying force. Air-filled pillows are used between the platens, and the module surfaces to uniformly distribute the alternating front and back force to the module surfaces.

5.5.2.1 The air pillows should not be excessively inflated. A pillow will not develop undesirable tensile stresses if pressurized appreciably less than its normal inflated thickness.

5.5.2.2 The opposing platen should not be so close to the module that it can interfere with the deformation of the module.

5.5.3 *Suction and Pressure Scheme*—This scheme is based on attaching the module to a frame and plate which in turn is connected to a pressure and suction system. With the module sealed and secured to the test fixture, a plenum is created. The required cyclic load is applied by creating a positive pressure or a suction within this plenum.

5.5.4 The pressure or suction shall be uniformly distributed over the module surfaces and controlled to 1440 ± 45 Pa.

5.5.5 The cycle rate shall not exceed 0.34 Hz.

5.5.6 A counter is recommended for counting test cycles.

6. Hazards

6.1 Each of the mechanical tests described herein involves risks associated with the tests and the possibility of catastrophic module failure.

6.1.1 The test fixtures that involve masses such as bricks, blocks, or lead shot bags should be designed with a net or tray located beneath the module to catch the weights and module debris should failure occur.

6.1.2 Protective footwear and safety glasses should be worn to protect the test personnel from falling weights and broken glass. Non-tempered glass can break with sharp-edged or pointed shards. Tempered glass breaks into a multitude of small, granular shaped pieces, and these can be propelled a long distance due to the release of the tension-compression pre-stresses created during the tempering process.

7. Procedures

7.1 *Electrical Tests*— Perform the following electrical tests before and after each of the test methods:

7.1.1 *Electrical Performance*—Measure each module in accordance with Test Methods E1036 to establish electrical performance including maximum power.

7.1.2 *Ground Path Continuity Test*—Test each module for ground path continuity in accordance with Test Methods E1462.

7.1.3 *Insulation Integrity Test*—Subject each module to a test of the electrical isolation capability in accordance with 7.1 and 7.2 of Test Methods E1462.

7.2 *Visual Inspection*—Visually inspect each module in accordance with Practice E1799 before and after each of the test procedures is performed.

7.3 Verify the ambient temperature is 20 ± 10°C.

7.4 *Twist Test Procedure:*

7.4.1 Connect the module leads to the open circuit fault detection apparatus and begin monitoring.

7.4.2 Fasten the module to the twist test fixture in accordance with the manufacturer's recommended fasteners and procedure.

7.4.3 Twist the module to the required displacement as follows (see Fig. 1):

$$h = 0.021\sqrt{L^2 + W^2} \tag{1}$$

where:

h = mounting point displacement measured perpendicular to the diagonal between mounting points, m,
L = length between mounting points, m, and
W = width between mounting points, m.

The displacement h corresponds to an angle of deformation of 1.2°.

7.4.4 Hold the module in the twisted position for 1 h. Discontinue the test if a failure occurs.

7.4.5 Remove the module from the test fixture.

7.4.6 Disconnect the module from the open circuit fault detection apparatus.

7.5 *Static Load Procedure, 2400 Pa Wind Load Test:*

7.5.1 Mount the module in the static load test apparatus.

7.5.2 Connect the module leads to the open circuit fault detection apparatus and begin monitoring.

7.5.3 Load the module. If the loading method involves the use of small bags or other discrete objects such as bricks, pre-weigh enough units to achieve the required total load to within 2 %.

7.5.3.1 The 2400 Pa load requires application of a total mass of 245 kg per square meter of module area.

7.5.3.2 If small bags or other discrete objects are used, particular attention should be given to the symmetry of the load application. Nonuniform (non-symmetric) loading can cause module failure at a load well below the level that it could normally withstand. (**Warning—**The test personnel should exercise care to always position themselves well outside of the zone where a module would fail.)

7.5.4 Hold the module in the loaded position for 1 h. Discontinue the test if a failure occurs.

7.5.5 Remove the load in a gradual and uniform manner.

7.5.6 Turn the module over and repeat 7.5.1 – 7.5.5 with the load on the opposite surface. If dual air bags are used, this can be accomplished by pressurizing the opposite bag.

7.5.7 Optionally, as required by the user or sponsor of the static load test,7.5.1 – 7.5.6 may be repeated for additional front and back loadings.

7.5.8 Disconnect the module from the open circuit fault detection apparatus.

7.5.9 Remove the module from the static load test apparatus.

7.6 *Static Load Procedure, 5400 Pa Snow and Ice Load Test:*

7.6.1 Mount the module in the static load test apparatus.

7.6.2 Connect the module leads to the open circuit fault detection apparatus and begin monitoring.

7.6.3 Apply the load to the front surface of the module. If the loading method involves the use of small bags or other discrete objects such as bricks, pre-weigh enough units to achieve the required total load to within 2 %.

7.6.3.1 The 5400 Pa load requires application of a total mass of 550 kg per square meter of module area.

7.6.3.2 If small bags or other discrete objects are used, particular attention should be given to the symmetry of the load application. Nonuniform (non-symmetric) loading can cause module failure at a load well below the level that it could normally withstand. (**Warning—**The test personnel should exercise care to always position themselves well outside of the zone where a module would fail.)

7.6.4 Hold the module in the loaded position for 1 h. Discontinue the test if a failure occurs.

7.6.5 Remove the load in a gradual and uniform manner.

7.6.6 Repeat 7.6.3 – 7.6.5 two more times to achieve a total of three front surface loadings.

7.6.7 Disconnect the module from the open circuit fault detection apparatus.

7.6.8 Remove the module from the static load test apparatus.

7.7 *Cyclic Load Test Procedure:*

7.7.1 Mount the module in the cyclic load test apparatus.

7.7.2 Connect the module leads to the open circuit fault detection apparatus and begin monitoring.

7.7.3 Begin the cycle operation. The test may be discontinued if a module failure occurs.

7.7.4 Continue cycling until a total of 10 000 cycles have been completed. The cycle rate shall not exceed 0.34 Hz.

7.7.5 Disconnect the module from the open circuit fault detection apparatus.

7.7.6 Remove the module from the cycling apparatus.

8. Report

8.1 In addition to the reporting requirements of Test Methods E1036 and E1462, and Practice E1799, report as a minimum the following data and information:

8.1.1 A brief description of the mechanical test apparatus,

8.1.2 Description of the open circuit fault detection apparatus.

8.1.3 A line drawing or photograph showing the module mounted in each apparatus, and the mounting details,

8.1.4 The measurement conditions or test parameters such as the twist deflection, static load level, cyclic load level, and the number of cycles,

8.1.5 Any deviations from these test methods such as interruptions during the cyclic load test, and any other test anomalies, and

8.1.6 Results of the open circuit fault monitoring.

9. Precision and Bias

9.1 The procedures described by these test methods do not produce numeric results that would be subject to ASTM requirements for evaluating the precision and bias of these test methods. However, the precision and bias of the electrical measurements, when performed in accordance with Test Methods E1036 and E1462, are subject to the provisions of those documents.

10. Keywords

10.1 cyclic loads; cycling; ice; load; mechanical integrity; modules; performance; photovoltaics; snow; solar energy; static; twist; wind

ANNEX

(Mandatory Information)

A1. MODULE OPEN CIRCUIT FAULT DETECTION

A1.1 A suggested apparatus that monitors the test module for open circuit fault conditions during testing is illustrated in Fig. A1.1.

A1.1.1 The bias current power supply has independent current and voltage limit adjustments.

A1.1.2 The bias current, I_{bias} , should be set to approximately three percent of the module's rated short-circuit current at standard reporting conditions, I_{sc}, and the bias voltage limit should be equal to the module open-circuit voltage, V_{oc}, ±0.5 V.

A1.1.3 If, during the test, the voltage at the test point ever becomes zero, the internal circuitry of the module is no longer continuous and a fault condition has occurred.

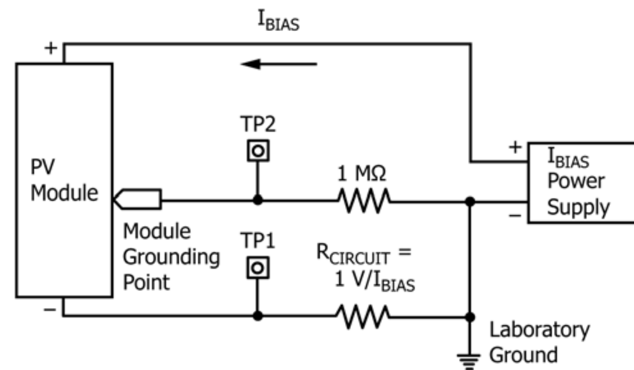

FIG. A1.1 Test Circuit for Detecting Open Circuit and Ground Fault Conditions