BS EN 62817:2015

BSI Standards Publication

Photovoltaic systems — Design qualification of solar trackers

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National foreword

This British Standard is the UK implementation of EN 62817:2015. It is identical to IEC 62817:2014.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, Photovoltaic Energy Systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

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NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 62817

March 2015

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English Version

Photovoltaic systems - Design qualification of solar trackers (IEC 62817:2014)

Systèmes photovoltaïques - Qualification de conception des suiveurs solaires
(IEC 62817:2014)

Sonnen-Nachführeinrichtungen für photovoltaische Systeme - Bauarteignung
(IEC 62817:2014)

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Foreword

The text of document 82/853/FDIS, future edition 1 of IEC 62817, prepared by IEC/TC 82 "Solar photovoltaic energy systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62817:2015.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2015-09-13
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2017-09-29

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Endorsement notice

The text of the International Standard IEC 62817:2014 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)
Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60068-2-6	-	Environmental testing -- Part 2-6: Tests - Test Fc: Vibration (sinusoidal)	EN 60068-2-6	-
IEC 60068-2-21	-	Environmental testing -- Part 2-21: Tests - Test U: Robustness of terminations and integral mounting devices	EN 60068-2-21	-
IEC 60068-2-27	-	Environmental testing -- Part 2-27: Tests - Test Ea and guidance: Shock	EN 60068-2-27	-
IEC 60068-2-75	-	Environmental testing -- Part 2-75: Tests - Test Eh: Hammer tests	EN 60068-2-75	-
IEC 60529	-	Degrees of protection provided by enclosures (IP Code)	-	-
IEC 60904-3	2008	Photovoltaic devices -- Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	EN 60904-3	2008
IEC 61000-4-5	2005	Electromagnetic compatibility (EMC) -- Part 4-5: Testing and measurement techniques - Surge immunity test	EN 61000-4-5	2006
IEC 62262	2002	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)	EN 62262	2002
ISO 12103-1	-	Road vehicles_- Test dust for filter evaluation_- Part_1: Arizona test dust	-	-
ISO/IEC 17025	-	General requirements for the competence of testing and calibration laboratories	EN ISO/IEC 17025	-

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC SYSTEMS – DESIGN QUALIFICATION OF SOLAR TRACKERS

FOREWORD

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International Standard IEC 62817 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this design qualification standard is based on the following documents:

FDIS	Report on voting
82/853/FDIS	82/877/RVD

Full information on the voting for the approval of this international standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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PHOTOVOLTAIC SYSTEMS – DESIGN QUALIFICATION OF SOLAR TRACKERS

1 Scope and object

This International Standard is a design qualification standard applicable to solar trackers for photovoltaic systems, but may be used for trackers in other solar applications. The standard defines test procedures for both key components and for the complete tracker system. In some cases, test procedures describe methods to measure and/or calculate parameters to be reported in the defined tracker specification sheet. In other cases, the test procedure results in a pass/fail criterion.

The objective of this design qualification standard is twofold.

First, this standard ensures the user of the said tracker that parameters reported in the specification sheet were measured by consistent and accepted industry procedures. This provides customers with a sound basis for comparing and selecting a tracker appropriate to their specific needs. This standard provides industry-wide definitions and parameters for solar trackers. Each vendor can design, build, and specify the functionality and accuracy with uniform definition. This allows consistency in specifying the requirements for purchasing, comparing the products from different vendors, and verifying the quality of the products.

Second, the tests with pass/fail criteria are engineered with the purpose of separating tracker designs that are likely to have early failures from those designs that are sound and suitable for use as specified by the manufacturer. Mechanical and environmental testing in this standard is designed to gauge the tracker’s ability to perform under varying operating conditions, as well as to survive extreme conditions. Mechanical testing is not intended to certify structural and foundational designs, because this type of certification is specific to local jurisdictions, soil types, and other local requirements.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-21, *Environmental testing – Part 2-21: Tests – Test U: Robustness of terminations and integral mounting devices*

IEC 60068-2-27, *Environmental testing – Part 2-27: Tests – Test Ea and guidance: Shock*

IEC 60068-2-75, *Environmental testing – Part 2-75: Tests – Test Eh: Hammer tests*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60904-3:2008, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 61000-4-5:2005, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 62262:2002, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 12103-1, *Road vehicles – Test dust for filter evaluation – Part 1: Arizona test dust*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. For additional tracker-specific terminology, see Clause 6.

3.1
photovoltaics
PV
devices that use solar radiation to directly generate electrical energy

3.2
concentrator photovoltaics
CPV
devices that focus magnified sunlight on photovoltaics to generate electrical energy. The sunlight could be magnified by various different methods, such as reflective or refractive optics, in dish, trough, lens, or other configurations

3.3
concentrator module
CPV module
group of receivers (PV cells mounted in some way), optics, and other related components, such as interconnections and mechanical enclosures, integrated together into a modular package. The module is typically assembled in a factory and shipped to an installation site to be installed along with other modules on a solar tracker

Note 1 to entry: The module is typically assembled in a factory and shipped to an installation site to be installed along with other modules on a solar tracker.

Note 2 to entry: A CPV module typically does not have a field-adjustable focus point. In addition, a module could be made of several sub-modules. The sub-module is a smaller, modular portion of the full-size module, which might be assembled into the full module either in a factory or in the field.

3.4
concentrator assembly
concentrator assembly consisting of receivers, optics, and other related components that have a field-adjustable focus point and are typically assembled and aligned in the field

EXAMPLE: A system that combines a single large dish with a receiver unit that is aligned with the focal point of the disk.

Note 1 to entry: This term is used to differentiate certain CPV designs from the CPV modules mentioned above.

4 Specifications for solar trackers for PV applications

The manufacturer shall provide the test lab, as part of its product marking and documentation, a table in the form specified below (see Table 1). The third column of Table 1 is for information purposes regarding this standard and is not intended to be part of an actual specification template provided to the test lab. See later clauses/subclauses of this standard for further explanation of individual specifications.

Some of the specifications within Table 1 are required to be provided by the manufacturer and verified by the test lab, whereas others are the sole responsibility of the test lab. Still other specifications in Table 1 are optional; however, if a tracker manufacturer chooses to include optional information, it shall be reported and measured in the specific way shown in Table 1 (and in some cases, reporting requirements are further described in the appropriate clause of this standard). Refer to the third column of Table 1 to determine the responsibility of the specification or optional status ("T" indicates test lab responsibility, "M" indicates manufacturer responsibility, and "O" indicates an optional parameter).

Table 1 – Tracker specification template

Characteristic	Example	Responsibility/Clause/Subclause
Manufacturer	The XYZ Company	(M)
Model number	XX1090	(M)
Type of tracker	CPV Tracker, Dual Axis	(M) 6.2, 6.3
Payload characteristics		
Minimum/maximum mass supported	100 kg/1 025 kg	(M) 6.8.3
Payload center of mass restrictions	0 m to 0,3 m distance perpendicular to mounting surface	(M) 6.8.3
Maximum payload surface area	30 m^2	(M) 6.8.3
Nominal payload surface area	28 m^2	(M)
Maximum dynamic torques allowed while moving	Azimuth (Θ_z):10 kN m Θ_x, Θ_y: 5 kN m [shall provide a set of diagrams to clarify torques and which axes they are relative to]	(M) 8.4.5
Maximum static torques allowed while in stow position	[shall provide a set of diagrams]	(M) 8.4.4, 8.4.5
Installation characteristics		
Allowable foundation	Reinforced concrete	(M) 6.6.2
Foundation tolerance in primary axis	± 0,5°	(O) 6.9
Foundation tolerance in secondary axis	± 0,5°	(O) 6.9
Installation effort	5 man-hours, 40 metric ton crane	(O) 6.8.8
Payload interface flexibility	The interface can be configured to mount modules from manufacturers "A", "B", and "C". Bolting configurations "X", "Y", and "Z" are allowable.	(O)
Electrical characteristics		
Includes backup power?	No	(M) N/A
Daily energy consumption	1,5 kWh	(T) 6.7.1
Stow energy consumption	1 kWh	(T) 6.7.2
Input power requirements	AC, 100 V to 240 V, 50 Hz to 60 Hz, 5 A	(M) No specifics defined
Effective (and apparent) peak power consumption tracking	500 W (550 VA)	(T) 8.3.2
Effective (and apparent) peak power consumption non-tracking	50 W (55 VA)	(T) 8.3.2
Effective (and apparent) peak power consumption stow positioning.	1 000 W (1 100 VA)	(T) 8.3.3

Characteristic	Example	Responsibility/Clause/Subclause
Tracking accuracy		
Accuracy, typical (low wind, min deflect point)	0,1°	(T) 7.4.6
Accuracy, typical (low wind, max deflect point)	0,3°	(T) 7.4.6
Accuracy, 95th percentile (low wind, min deflect point)	0,5°	(T) 7.4.6
Accuracy, 95th percentile (low wind, max deflect point)	0,8°	(T) 7.4.6
Mean wind speed during the “low wind” test conditions	3,1 m/s	(T) 7.4.6
Accuracy, typical (high wind, min deflect point)	0,7°	(T) 7.4.6
Accuracy, typical (high wind, max deflect point)	1,0°	(T) 7.4.6
Accuracy, 95th percentile (high wind, min deflect point)	1,1°	(T) 7.4.6
Accuracy, 95th percentile (high wind, max deflect point)	1,6°	(T) 7.4.6
Mean wind speed during the “high wind” test conditions	5,2 m/s	(T) 7.4.6
Weight and area of payload installed during testing	500 kg payload evenly distributed over a 50 m^{2} area	(T) 7.4.2.1
Payload center of mass installed during testing	Payload center of mass 0,2 m above the module mounting surface	(T) 7.4.2.1
Control characteristics		
Control algorithm	Hybrid	(M) 6.5
Control interface	None	(M) 6.8.9
External communication interface	Ethernet/TCP-IP	(M) No specific description
Emergency stow provided?	Yes, at wind speeds 14 m/s	(M) 6.6.3.1
Stow time	4 min	(M) 6.6.4
Clock accuracy	1 s per year	(M) N/A
Hard limit switches	Not included	(M) 7.2.3
Mechanical design		
Actuation type	Distributed	(M) 6.4.1
Drive type	Electric	(M) 6.4.3
Actuators	DC motor, 185 W	(M) No specific description
Range of motion, primary axis	± 160° azimuth	(M) 6.6.3.3
Range of motion, secondary axis	10° to 90° elevation	(M) 6.6.3.3
System stiffness	See test lab report on measurement locations, applied loads, and measured deflections	(T),(O) 6.9.4, 8.4.3
Drive train torsional stiffness	See plot of angular displacement versus applied torque	(T) 8.4.4, Figure 9
Backlash	0,1° maximum	(T) 6.9.3, 8.4.4
Environmental conditions		
Maximum allowable wind speed during tracking	14 m/s	(M) 6.12.4

Characteristic	Example	Responsibility/Clause/Subclause
Maximum allowable wind speed in stow	40 m/s	(M) 6.12.5
Temperature operational range	–20 °C to +50 °C	(M) 6.12.1
Temperature survival range	–40 °C to +60 °C	(M) 6.12.2
Snow rating	Up to 20 kg/m^2 of snow load allowed	(M) 6.12.6
Maintenance and Reliability		
Maintenance schedule	Grease application every 12 months (0,75 man-hours required) Drive train fluid change every 3 years (1,25 man-hours required)	(O)
MTBF	3,5 years	(O) 6.11.2
MTTR	2 h (azimuth or elevation motor) (list components that are expected to need repair or replacement within a 10-year period)	(O) 6.11.4

For an alternate template for the presentation of accuracy specifications, see Table 2.

5 Report

A certified report of the qualification tests, with measured performance characteristics and details of any failures and re-tests, shall be prepared by the test agency in accordance with ISO/IEC 17025. The report shall contain the specification sheet per Table 1. Each certificate or test report shall include at least the following information:

a) a title;

b) name and address of the test laboratory and location where the tests were carried out;

c) unique identification of the certification or report and of each page;

d) name and address of client, where appropriate;

e) description and identification of the item tested;

f) characterization and condition of the test item;

g) date of receipt of test item and date(s) of test, where appropriate;

h) identification of test method used;

i) reference to sampling procedure, where relevant;

j) any deviations from, additions to, or exclusions from, the test method and any other information relevant to a specific test;

k) measurements, examinations and derived results supported by tables, graphs, sketches, and photographs as appropriate, and any failures observed;

l) a statement of the estimated uncertainty of the test results (where relevant);

m) a signature and title, or equivalent identification of the person(s) accepting responsibility for the content of the certificate or report, and the date of issue;

n) where relevant, a statement to the effect that the results relate only to the items tested;

o) a statement that the certificate or report shall not be reproduced except in full, without the written approval of the laboratory.

A copy of this report shall be kept by the manufacturer for reference purposes.

6 Tracker definitions and taxonomy

6.1 General

Solar trackers are mechanical devices used to track or follow the sun across the sky on a daily basis. Although a solar tracker can be used for many purposes, the scope of this standard is focused on solar trackers for photovoltaic (PV) applications. In PV applications, the primary purpose of the tracker is to enhance the capture of available solar irradiance to be converted to electricity. Photovoltaic trackers can be classified into two types: standard PV trackers and concentrator photovoltaic (CPV) trackers. Each of these tracker types can be further categorized by the number and orientation of their axes, their actuation architecture and drive type, their intended applications, and their vertical supports and foundation type.

6.2 Payload types

6.2.1 Standard photovoltaic (PV) module trackers

6.2.1.1 Uses

Standard PV trackers are used to minimize the angle of incidence between incoming light and a PV module. This increases the amount of energy produced from a fixed amount of power-generating capacity.

6.2.1.2 Type of light accepted

Photovoltaic modules accept both direct and diffuse light from all angles. This means that systems implementing standard PV trackers produce energy even when not directly pointed at the sun. Tracking in standard PV systems is used to increase the amount of energy produced by the direct component of the incoming light.

6.2.1.3 Accuracy requirements

In standard PV systems, the energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the module. Thus, trackers that have accuracies of ± 5° can deliver 99,6 % of the energy supplied by the direct beam. As a result, high-accuracy tracking is not typically used.

6.2.2 Concentrator photovoltaic (CPV) module trackers

6.2.2.1 Uses

Concentrator photovoltaic trackers are used to enable the optics used in CPV systems. These trackers typically align CPV optical elements with the sun's direct beam with a higher degree of accuracy than standard PV trackers.

6.2.2.2 Type of light accepted

Direct solar radiation, as opposed to diffuse solar radiation, is the primary energy source for CPV modules. Optics are designed specifically to focus the direct radiation on PV cells. If this focus is not maintained, power output drops substantially.

If the CPV module concentrates in one dimension, then single-axis tracking is required. If the CPV module concentrates in two dimensions, then two-axis tracking is required.

6.2.2.3 Accuracy requirements

In concentrator modules, tracking accuracy requirements are typically related to energy production through the module acceptance angle. When the sun-pointing error is less than the acceptance angle, the modules will typically deliver 90 % or more of the rated power output.

6.3 Rotational axes

6.3.1 General

Photovoltaic trackers can be grouped into classes by the number axes and orientation of the primary axis.

6.3.2 Single-axis trackers

6.3.2.1 General

Single-axis trackers have one degree of freedom that acts as an axis of rotation.

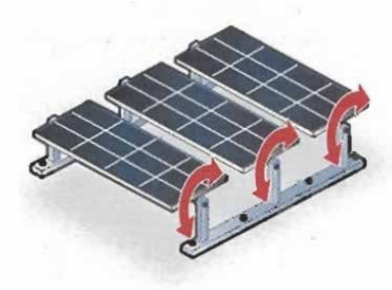
6.3.2.2 Single-axis tracker implementations

6.3.2.2.1 General

There are several common implementations of single-axis trackers. These include horizontal single-axis trackers, vertical single-axis trackers, and inclined single-axis trackers.

6.3.2.2.2 Horizontal single-axis tracker (HSAT)

The axis of rotation for a horizontal single-axis tracker is horizontal with respect to the ground.



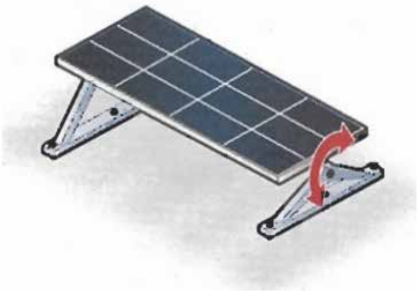
6.3.2.2.3 Vertical single-axis tracker (VSAT)

The axis of rotation for vertical single-axis trackers is vertical with respect to the ground. These trackers rotate from east to west over the course of the day.

6.3.2.2.4 Inclined single-axis tracker (ISAT)

All trackers with axes of rotation between horizontal and vertical are considered inclined single-axis trackers. Tracker inclination angles are often limited to reduce the wind profile and decrease the elevated end’s height off the ground.

The polar-inclined single-axis tracker (PISAT) is a specific version of the inclined single-axis tracker. In this particular implementation, the inclination angle is equal to the latitude of the installation. This aligns the tracker's axis of rotation with the Earth's axis of rotation.



6.3.2.3 Orientation – cardinal direction

The axis of rotation of single-axis trackers is typically aligned along a true north meridian. It is possible to align them in any cardinal direction with advanced tracking algorithms.

6.3.2.4 Module orientation with respect to rotational axis

The orientation of the module with respect to the tracker axis is important when modelling performance.

Horizontal and inclined single-axis trackers typically have the face of the module oriented parallel to the axis of rotation. As a module tracks, it sweeps a cylinder that is rotationally symmetric around the axis of rotation.

Vertical single-axis trackers typically have the face of the module oriented at an angle with respect to the axis of rotation. As a module tracks, it sweeps a cone that is rotationally symmetric around the axis of rotation.

6.3.3 Dual-axis trackers

6.3.3.1 General

Dual-axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered the primary axis. The axis that is referenced to the primary axis can be considered the secondary axis.

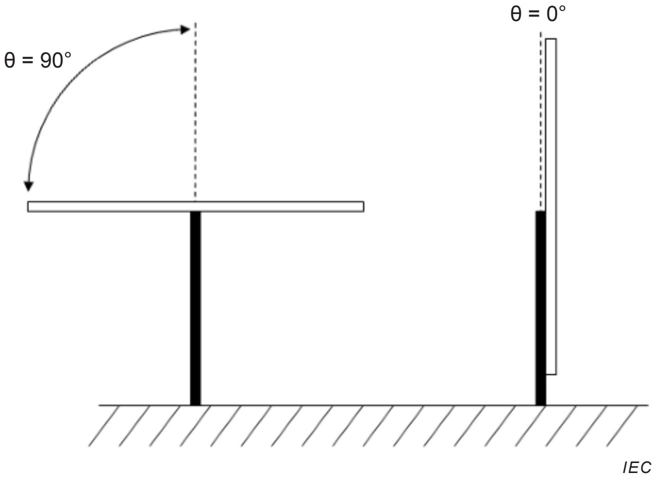
6.3.3.2 Dual-axis tracker implementations

6.3.3.2.1 General

There are several common implementations of dual-axis trackers. They are classified by the orientation of their primary axes with respect to the ground. One common implementation is a vertical primary dual-axis tracker (VPDAT) (also called azimuth-elevation).

A convention for azimuth angle is "degrees east of north" (e.g., 0° azimuth is pointing north, and 90° azimuth is pointing east).

A convention for elevation angle is "degrees up from the horizon," as illustrated below in Figure 1. Zenith angle is the complement of elevation angle (zenith = 90° – elevation).



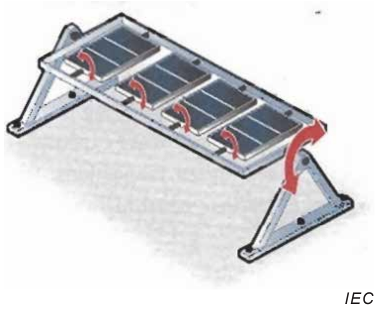
NOTE θ = elevation angle = 0° (zenith angle = 90°) occurs when a vector normal to the module face is pointing to the horizon. Elevation angle = 90° (zenith angle = 0°) occurs when the module is facing the sky.

Figure 1 – Convention for elevation angle

The above sign conventions are assumed to be the ones used to describe angles, but a different convention can be used as long as it is described. For example, the range of motion of a tracker could be described as "azimuth from +20° to +340°" or alternately, "azimuth ± 160° from south".

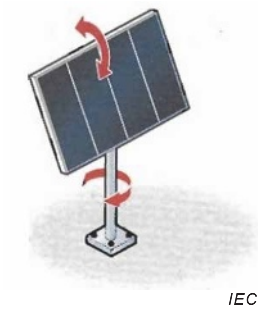
6.3.3.2.2 Horizontal primary dual-axis tracker

A horizontal primary dual-axis tracker (HPDAT) has its primary axis horizontal to the ground. The secondary axis is then typically normal to the primary axis.



6.3.3.2.3 Vertical primary dual-axis tracker

A vertical primary dual-axis tracker (VPDAT) has its primary axis vertical to the ground. The secondary axis is then typically normal to the primary axis.



6.3.3.2.4 Inclined primary dual-axis tracker

An inclined primary dual-axis tracker (IPDAT) has its primary axis between vertical and horizontal. The secondary axis is then typically normal to the primary axis.

6.3.3.3 Orientation – cardinal direction

The axes of rotation of horizontal primary dual-axis trackers are typically aligned either along a true north meridian or an east-west line of latitude. It is possible to align them in any cardinal direction with advanced tracking algorithms.

6.3.3.4 Module orientation with respect to rotational axes

The orientation of the module with respect to the tracker axis is important when modelling performance. Dual-axis trackers typically have modules oriented parallel to the secondary axis of rotation.

6.4 Actuation and control

6.4.1 Architecture

6.4.1.1 General

There are two common actuation and control architectures: distributed actuation and ganged actuation. These are implemented in many ways.

6.4.1.2 Distributed actuation

In a distributed actuation architecture, each tracker and each axis of rotation is independently actuated and controlled.

6.4.1.3 Ganged actuation

In a ganged actuation architecture, many axes of rotation are simultaneously driven with a single actuation system. This can be multiple axes on a single tracker or multiple trackers in an array.

6.4.2 Drive train

The drive train includes all components of the tracker system that transfer mechanical motion to the payload interfaces, including all axes of rotation. Typically, this would include gears, motors, actuators, hydraulic/pneumatic rams, transmission, and linkages. The drive train does not include the electronic controls or the payload interface.

6.4.3 Drive types

6.4.3.1 General

There are three typical drive types used with solar trackers.

6.4.3.2 Electric drive

Electric drive systems transfer electrical energy to AC motors, DC brushed motors, or DC brushless motors to create rotational motion. These motors are typically interfaced with gearboxes that reduce the rotational speed in exchange for additional torque. The final gearbox stage or a leverage delivers either rotary or linear motion that is used to drive a tracker axis and increase axis stiffness.

6.4.3.3 Hydraulic drive

Hydraulic drive systems use pumps to generate hydraulic pressure. The hydraulic pressure is transferred through valves (such as proportional or ON/OFF), pipes, and hoses to a hydraulic motor or cylinder. The hydraulic motor and cylinder adjust the mechanical advantage as needed to deliver the rotary or linear motion to drive a tracker axis.

6.4.3.4 Passive drive

Passive-drive systems use differential fluid pressure to drive a tracker axis. The pressure differential is created by thermal gradients created by differential shading. The tracker moves to bring the pressure differentials to equilibrium.

6.4.4 Drive train torque

6.4.4.1 Operational torque

Operational torque is the maximum torque that can be applied to the tracker through wind or other forces while the drive train is actively moving (this could be tracking the sun or moving to stow or another position). Operational torque can be different for each axis of rotation.

6.4.4.2 Holding torque

Holding torque is the maximum torque that can be applied to the tracker when the drive train is in a fixed position. The tracker is expected to neither move nor backdrift under this torque. Holding torque can be different for each axis of rotation. Holding torque does not apply if an axis is designed to freewheel in a particular position.

6.4.4.3 Destructive torque

Destructive torque is the torque level that when exceeded will cause permanent deflection or destruction to tracker components. Destructive torque can be different for each axis of rotation.

6.5 Types of tracker control

6.5.1 Passive control

Passive solar tracking typically relies on environmental forces to produce changes in fluid density, which provide internal forces that can be used for mechanical advantage to position the payload.

6.5.2 Active control

6.5.2.1 General

Active solar tracking uses supplied power to drive circuitry and actuators (motors, hydraulics, and others) to position the payload.

6.5.2.2 Open-loop control

Open-loop control is an active method of tracking that does not use direct sensing of the sun position or module power as feedback. Rather, it uses mathematical calculations of the sun position (based on the time of day, date, location, and so on) to determine where the tracker should be pointing and drives actuators accordingly.

Note that open-loop control in this context does not imply that the actuators themselves do not provide feedback; the actuators could be servo motors with encoders and could themselves be controlled via a closed-loop controller.

Open loop in the context of tracker control refers to the control algorithm having no direct feedback on the actual tracking error.

6.5.2.3 Closed-loop control

This is an active method of tracking that uses some sort of feedback (such as an optical sun-position sensor or the module power output) to determine how to drive the actuators and position the payload.

6.5.2.4 Hybrid control

This is an active method of tracking that combines the mathematical sun-position calculations (open-loop ephemeris code) with the type of sensor data used in a closed-feedback loop. There are many different approaches to hybrid control.

6.5.3 Backtracking

Backtracking refers to intentionally positioning trackers somewhat off-sun, typically to reduce shading from adjacent trackers in a close-packed installation during the early morning and late afternoon when the sun is low on the horizon.

One method involves moving all the trackers in a field to a slightly higher elevation angle to avoid shading. Another approach is for every other row to be inactive and positioned at 90° elevation (pointing at the sky) to allow the other rows a clear line of sight to the sun without shading. This is useful mainly in designs that do not have access to enough land area to be spaced far enough apart to avoid shading in the early morning and late afternoon. Backtracking is typically not applicable to CPV.

6.6 Structural characteristics

6.6.1 Vertical supports

6.6.1.1 General

Vertical supports transfer the load of the structure to the foundation. There are two common types of vertical supports.

6.6.1.2 Pole-mounted trackers

A pole-mounted tracker transfers the load to the foundation via one or more poles. These poles attach to or continue into one or more foundations.

All types of trackers (single axis and dual axis) can be mounted on poles.

6.6.1.3 Carousel-mounted trackers

A carousel-mounted tracker transfers the load to the foundation via a ring. This ring is then attached to or contacts the foundation at multiple points.

Carousel-mounted trackers typically have a vertical primary axis.

6.6.2 Foundation types

6.6.2.1 General

The load placed on the tracker structure shall be sustained through its foundation.

Trackers can be mounted on roofs, ground/earth, and water and will be subject to location-specific loading. As a result, there are many types of foundations used with trackers. The foundation type used will depend on site-specific characteristics and the codes of the local jurisdiction.

Foundation types are often categorized by whether or not they penetrate into the mounting surface.

6.6.2.2 Penetrating foundations

6.6.2.2.1 Pile foundations

Pile foundations (also known as deep foundations) come in a wide variety of types. These include but are not limited to concrete piles, driven piles, and drilled piles.

Pile foundations are common in ground-mounted and water-mounted applications. Hole diameters, depth, concrete mixtures, rebar requirements, thread type, and other characteristics are all determined by local site conditions.

6.6.2.3 Non-penetrating foundations

6.6.2.3.1 Ballasted foundations

Ballasted foundations (also known as shallow foundations) come in a wide variety of types.

Ballasted foundations are found in ground-mount and roof-mount applications. The area in contact with the surface, total mass, material type, rebar requirements, and other characteristics are all determined by local site conditions.

6.6.3 Tracker positions

6.6.3.1 Stow

The stow position is the position the tracker moves to when adverse weather conditions (e.g., high wind or heavy snow) are present or expected to avoid loads that might damage the tracker or payload. Not all trackers will have a stow position, and the exact position will vary depending on the tracker design. It is possible that one tracker can have multiple stow positions.

6.6.3.2 Maintenance

The maintenance position is the position to which the tracker moves for operations such as cleaning, module installation, and servicing. It could be the same position as the stow position or a different position, and there could be multiple maintenance positions. Not all trackers will have a maintenance position. When in this position, there shall be a safety interlock preventing sudden tracker motion without operator interaction. This safety interlock can be instituted by various means as long as it requires operator interface to release.

6.6.3.3 Range of motion

The range of motion is defined by the maximum motion of the tracker in each direction, in each axis.

For example, a primary axis might have a range of motion of ± 135° from true south [or in the reference frames defined above, +45° to +315° azimuth (east of north)]. An elevation-style secondary axis might have a range of motion of 0° to 90°.

The range of motion specified in the requirements of Table 1 shall be tested and documented.

Note that the range of motion is not only defined by mechanical limits: the presence of electronic limit switches or software settings may be used to further restrict the range of motion for reasons such as safety or reduction of shading.

If the tracker includes a controller, the range of motion shall refer to the maximum range of motion that can be commanded by the combination of hardware and software.

6.6.4 Stow time

The stow time is the time it takes for the tracker with a standard payload to move from the position farthest from the stow position to the stow position. If there are multiple stow positions, then stow time will refer to the time it takes to move to the stow position of farthest extreme from on-sun tracking range. The stow position shall be reported.

6.7 Energy consumption

6.7.1 Daily energy consumption

The daily energy consumption of a tracker is defined as the amount of energy in kWh that is required to perform a full 24 h day of tracking (from start to stop at a typical tracking speed and back to start by whatever speed is standard for that tracker) carrying a standard load. The energy consumption will likely vary based on the wind loading and possibly also on cloud cover and other weather conditions. The energy consumption will also vary depending on the time of year.

6.7.2 Stow energy consumption

The stow energy consumption of a tracker is defined as the amount of energy in kWh that is required for the tracker to move from the position farthest from the stow position to the stow position.

6.8 External elements and interfaces

6.8.1 Foundation

The foundation is the support structure that is nominally fixed with respect to the terrain. It is equivalent to the mechanical “ground” symbol.

6.8.2 Foundation interface

The foundation interface attaches the tracker to the ground or rooftop. The tracker design will allow a maximum misalignment between the tracker and the foundation for correct operation.

6.8.3 Payload

The payload is the object being moved by the tracker, typically an array of PV or CPV modules combined with some mounting structure (but not including the tracker itself). The tracker shall specify a minimum and maximum weight of the carried payload, as well as any restrictions on weight distribution and center of mass. The payload surface area is considered the basic length multiplied by the width of a module multiplied by the number of modules installed on the tracker. For example, note that this is not the actual surface area of an array of modules that have domed or curved lenses.

Accuracy testing (detailed in 7.4.6) will be carried out with an installed payload, either an array of actual modules or an array of weights that simulate the mass, mass distribution, and wind resistance of these modules.

6.8.4 Payload interface

The payload interface is the boundary between the payload and the tracker. It is defined by the method of attachment between the payload and the tracker and the method(s) for transmitting loads between the payload and the tracker.

6.8.5 Payload mechanical interface

Provisions for managing wires across rotational interfaces are considered a mechanical interface issue, not an electrical one.

6.8.6 Payload electrical interface

The payload electrical interface includes any electrical connections between the tracker and the payload. Generally, electrical signals are not passed through trackers (except in a purely mechanical manner). For some tracker control schemes, however, electrical behaviour(s) of the payload are used as feedback, e.g., PV module output current or module output power.

6.8.7 Grounding interface

The grounding interface includes connections for the tracker to be grounded in case of a fault and for electrostatic discharge (ESD) protection.

6.8.8 Installation effort

6.8.8.1 General

The installation effort includes the man-hours necessary to install the tracker. This shall also include specialty equipment needed to install the tracker.

6.8.8.2 Range of latitude installation

This specifies the range of latitudes between 0° and 90° that the tracker design accommodates.

If the tracker control software is only designed for operation in one hemisphere, this shall also be stated.

6.8.9 Control interface

6.8.9.1 Human/manual interface

This describes any methods for an operator who is physically present at the tracker to control some of the functions. This could include switches or buttons to control motors, or an emergency stop button to halt motion. Each tracker design may provide different levels of manual interface.

6.8.9.2 Remote interface

A remote interface for the tracker could involve wired or wireless communications and a variety of communications protocols and user interfaces. One example is a remote web-based interface.

6.9 Internal tolerances

6.9.1 Primary-axis tolerance

Primary-axis tolerance is the total acceptable installation error between the specified primary-axis vector (e.g., vertical, horizontal, inclined at site latitude) and the actual vector of the primary axis upon final installation. The tolerance can be defined in milliradians or degrees (see Figure 2).

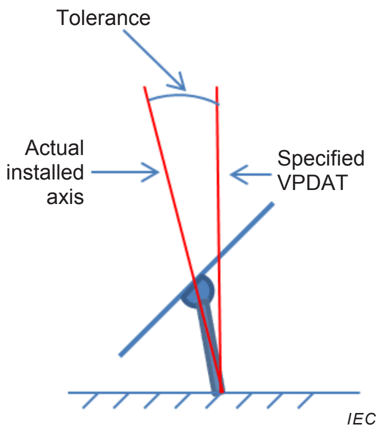


Figure 2 – Illustration of primary-axis tolerance for VPDAT

The tolerance is also used as a method to indicate how accurately the primary axis shall be installed. For example, a tracker manufacturer might specify that the tracker will perform within specification as long as the primary axis is installed within 1° of the nominal position.

6.9.2 Secondary axis tolerance

The secondary axis tolerance is defined as the total acceptable error, in milliradians or degrees, between the ideal or specified secondary axis vector and the actual installed vector that is the secondary axis.

6.9.3 Backlash

Backlash is defined by the free movement in the drive system of the tracker. Backlash will be specified relative to each axis of motion for the given tracker and will specify the complete envelope of free movement, in degrees, for each axis. Backlash can occur due to clearance between mating teeth, movement in pin or other mechanical joints, elasticity in hydraulic fluid, or other mechanisms that are system specific, and may manifest themselves more significantly under high winds.

6.9.4 Stiffness

Stiffness is inversely proportional to the deformation of the specific part under load. The stiffness of the tracker may be identified by mounting the tracker to a ground or to a full-reaction ground unit that is considered to have infinite stiffness (i.e., large metal plate on a concrete floor); a lever arm is placed coincident to each axis to be tested by movement by an external force. Stiffness is influenced by the gear drive system, the frame and the modules attached to it, and the pedestal. Many trackers are designed to be compatible with a wide range of modules; therefore, it is valuable to measure the stiffness independent of the module payload. It is suggested that each axis should be tested independently to determine the full stiffness of the system.

6.10 Tracker system elements

6.10.1 Mechanical structure

The mechanical structure supports the photovoltaic modules or assemblies. It provides the strength and stiffness necessary to survive exposure conditions traceable to the foundation.

6.10.2 Tracker controller

The tracker controller consists of all control electronics such as the microprocessor, motor drivers, power supply/transformer, and communication links. It usually does not include positional sensors, such as encoders or limit switches.

6.10.3 Sensors

Sensors include ones that allow for closed-loop control (sun-position sensor, module power output) and ones that allow precise positioning of the drive train (e.g., encoders, inclinometers), as well as ones that provide additional weather data for either system control or monitoring (e.g., temperature, wind speed and direction).

6.11 Reliability terminology

6.11.1 General

Failure: any state of the tracker that does not meet the requirement to track during daily use.

Critical failure: any state of the tracker that causes a safety concern or major damage to the tracker system or foundation.

Maintenance delay: time during which the tracker is not functional due to waiting for parts or service personnel.

Facility delay: time during which the tracker is not functional due to no power, water, or other facility issues.

Total downtime: maintenance delay + facilities delay + repair time.

Tracker uptime: time that the tracker is functional.

Repair time: time for service personnel to repair equipment once parts and people are on site.

% tracker uptime = tracker uptime / [total time – (maintenance delay + facility delay)] × 100

6.11.2 Mean time between failures (MTBF)

MTBF is defined as the average number of hours the tracker operates without failure requiring maintenance. It may be constructed of yearly data and shall be bounded by a statistical analysis. Each component of the tracker should have clearly identified MTBF data. However, the combination of these data into one statistical metric shall be done with an averaging scheme, representing the tracker as a system of components. Tracker documentation shall describe the MTBF strategy in terms of this averaging.

Estimated MTBF = tracker uptime / number of tracker failures that occur during productive time

6.11.3 Mean time between critical failures (MTBCF)

MTBCF is defined as the average number of hours the tracker operates without a failure that can be considered a safety hazard or that causes major damage to the tracking system or foundation. It may be constructed of yearly data and shall be bounded by a statistical analysis. Each component of the tracker should have clearly identified MTBF data. However, the combination of these data into one statistical metric shall be done with an averaging scheme, representing the tracker as a system of components. Tracker documentation shall describe the MTBCF strategy in terms of this averaging.

Estimated MTBCF = tracker uptime / number of tracker critical failures that occur during productive time.

6.11.4 Mean time to repair (MTTR)

MTTR is how long it takes, on average, for a piece of the solar tracker to be removed, fixed, and reinstalled, or removed and reinstalled with a new unit. It is constructed of yearly data and shall be bounded by a statistical analysis. Each component of the tracker should have clearly identified MTTR data.

Estimated MTTR = total repair time for tracker-related failure / # of tracker-related failures

6.12 Environmental conditions

6.12.1 Operating temperature range

This bounds the temperature in which the design may be operated while still meeting the other product specifications, e.g., accuracy.

6.12.2 Survival temperature range

This bounds the temperatures within which the design can be installed without damage, although possibly without continuing to meet the other product specifications—for example, accuracy or speed might be reduced.

6.12.3 Wind speed

Wind speeds reported by the manufacturer in the specification sheet shall correspond to a 10 m height and an air density of 1,225 kg/m^3.

Regarding wind speed measurements associated with specific tests in this standard, two options, described below, are allowable for wind speed measurements. Regardless of the option chosen, the wind speed data shall be reported in 1 min increments for the 10 min mean speed at a 10 m height. Wind speeds measured at tracker test height shall be translated to a 10 m height using formula (1). V_{test} is the wind speed in m/s at the height h, and V_{10} is the wind speed at a 10 m height. For heights less than or equal to 4,6 m, h is held constant at 4,6.

$$V_{\text{test}} = V_{10}(h/10)^{0,15} \qquad h > 4,6 \tag{1}$$

In option 1, the wind speed shall be measured at a 10 m height with no obstructions taller than 3,3 m within a 200 m radius of the wind-measuring device. The tracker shall be located within 400 m of the wind-measurement device and there shall be no obstructions between the tracker and the wind-measurement device that would create or indicate separate wind conditions at each location. For large trackers with maximum heights near or above 10 m, calculation/documentation shall validate that the tracker is located such that its turbulence wake has no more than a 10 % impact on the wind speed measurement. This can be calculated by assuming that wind speed returns to at least 90 % of its original value after a distance of 25 times the maximum height of the tracker. To ensure that the 10 m height wind speed measurement is valid at the tracker location, the tracker shall have no obstructions surrounding it that would reduce the wind speed by more than 10 % at the tracker location. In other words, there shall be no objects within a distance of the tracker that is equal to 25 times the object's height. Objects with a height less than 1/3 of the mean height of the tracker payload (usually the elevation axis) and objects with a horizontal width less than 16 cm (a mast used for a wind sensor) shall be excluded.

In option 2, the wind speed and wind direction shall be measured at a height that is within 1,5 m of the mean height of the tracker payload. The wind sensors shall be located on the prevailing-wind side of the tracker at a horizontal distance greater than R/tan15° from the center of the tracker (where R is the radius of the azimuth-tracking plane or equivalent). There shall be no obstructions between the wind sensors and the tracker and no surrounding obstructions that would indicate the tracker would see wind speeds that differ more than 10 % from the wind sensor. Data shall not be used for tracking accuracy calculations for wind directions that are (180± 20)° different than the prevailing direction (i.e., wind directions that result in the sensor being located within the turbulence wake of the tracker). The wind speed data shall be corrected to a 10 m height.

6.12.4 Maximum wind during operation

The maximum 10 m height wind speed that the tracker can withstand while continuing to track the sun or move in other desired directions. It is recommended that this rating also specifies conditions under which this wind rating applies. (No specifics are listed for such conditions because standardization of these conditions vary by country. For example, in Europe, this might be listed as "terrain slope A" and "surface condition B," whereas in the United States, this might be "surface roughness B" and "exposure category B.")

6.12.5 Maximum wind during stow

The maximum 10 m height wind speed under which the tracker can withstand while in the stow position.

6.12.6 Snow load

The tracker shall be rated for a maximum snow load in kg/m^2. This snow loading shall be in addition to the maximum rated payload (see 6.8.3). This standard does not address the combination of wind and snow loadings.

7 Tracker accuracy characterization

7.1 Overview

This clause makes a clear distinction between instantaneous pointing error and reported tracking accuracy. Methods are described for measuring pointing error and a description is given on how to process the data to statistically report tracking accuracy. Tracking accuracy characterization is considered optional for single-axis trackers. If a single-axis tracker is subjected to tracking-accuracy characterization, the manufacturer shall be permitted to present a modified plan to the test lab that is appropriate for a single axis. The modified plan shall be documented in the test report.

7.2 Pointing error (instantaneous)

The pointing error of a solar tracker is the angle between the pointing vector of the module (in many cases, this is the vector normal to the face of the module) and the pointing vector of the sun (see Figure 3). Note that pointing error is not just the accuracy of a subsystem (such as the gear box, algorithm, or controller), but rather, it is the sum of all subsystem errors, that is, the actual difference in angle between where the tracker is pointing and where the sun is at that moment in time.

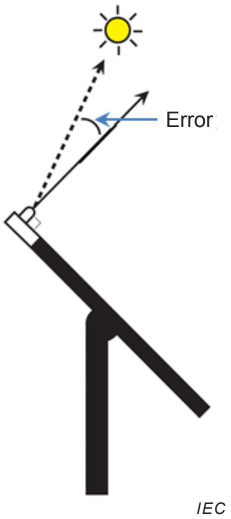


Figure 3 – General illustration of pointing error

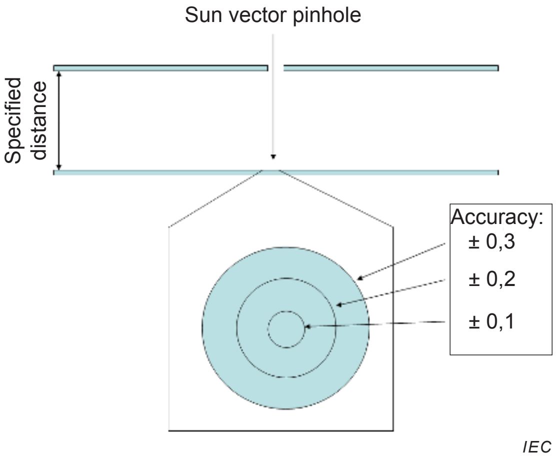
7.3 Measurement

7.3.1 Overview

Pointing error shall be directly measured (not theoretically calculated from a model of the tracker or from the values reported by the tracker controller). Pointing error is measured with a sensor that mounts on the tracker in the same plane as the solar modules and measures the relative sun position. Measurement of pointing error pertains to the complete tracker system including mechanical components and the electronic control system. If any component is modified as part of a design iteration and this component has a reasonable potential to impact tracking-accuracy metrics, then pointing error shall be remeasured and tracking-accuracy metrics reported again.

7.3.2 Example of experimental method to measure pointing error

Experimental tracking accuracy is a method of determining actual pointing error of a tracker over a specified time. Experimental tracking accuracy measurements can be obtained by using two flat parallel planes that are a specified distance from each other, one having a pinhole in it so as to project the sun's location in a measurable format (see Figure 4 below).



NOTE The figure shows two flat parallel plates at a specified distance, one having a pinhole for sunlight to be tracked on specified-diameter circles that ultimately measure 0,1°, 0,2°, and 0,3° accuracy rings (more, if necessary).

Figure 4 – Example of experimental method to measure pointing error

A pinhole system is just one example of a method to project tracking error on a detector surface; optics or other methods are equally viable. The projected image of the sun may be recorded and analyzed with photosensitive paper, a photodiode array, an image sensor, or other appropriate sensors. Typically, the device that measures pointing error outputs error in two axes (± azimuth error and ± elevation error). The actual pointing error is always positive and is the resultant vector of the error in both axes.

Another alternative is to measure the current generated by the sun's direct beam on split detectors. When pointing error is zero, each detector should receive equal radiation and therefore generate equal currents. When pointing error is not zero, one sensor or the other will generate more current. A calibration factor and a simple calculation translate the measured currents to a pointing error.

7.3.3 Calibration of pointing error measurement tool

The tool used to measure pointing error (whether it be a photodiode, camera, or other sensor) shall be separately calibrated to an accuracy at least three times the tracker accuracy it will be used to measure. For example, if a tracker pointing error of 0,06° is reported, then the measurement device shall be calibrated and verified to 0,02° or better accuracy. The required accuracy is only applicable to the field of view necessary for the tracker under test. For example, a tracking accuracy monitor may have a full field of view of ± 3°. This monitor could have an accuracy of ± 0,02° for the field of view of ± 1° but have an accuracy of ± 0,06° for the full ± 3° field of view. When a given test only uses the ± 1° field of view, the accuracy of ± 0,02° is applicable.

The calibration shall be performed either with sunlight or under an artificial light source with intensity at least 100 W/m^2 and collimation 1° or smaller.

Accuracy under at least 10 different sun locations (ranging from the center to the corner of the sensor field of view) shall be verified during this calibration process.

7.4 Calculation of tracker accuracy

7.4.1 Overview

- Measure data using a pointing error sensor and measurement method (as described earlier) over a minimum of 5 days.
- Divide the data into a high and low wind speed bin based on a 4 m/s threshold.
- Filter the data (e.g., it may be necessary to remove data taken during low irradiance conditions; see 7.4.4).
- Calculate statistics on each set of data and report tracking accuracy.

7.4.2 Data collection

7.4.2.1 Tracker setup

The tracker should be installed according to the manufacturer recommendations.

The maximum rated payload shall be installed on the tracker for accuracy testing with mass per area and center of mass location matching the end application within ± 20 %.

Payload weight, center of mass, number of units, and any air gaps between units should be documented in the test results, and a photograph of the test setup shall be included.

7.4.2.2 Sensor mounting

One pointing-error sensor shall be mounted on the estimated location for maximum deflection of the tracking plane (typically, the corner or edge of the tracking plane).

A second pointing-error sensor shall be mounted in the center of the tracking plane or the point of minimum deflection.

The following procedure shall be followed for the alignment of said sensors. With the sensors mounted and the tracker following the sun, monitor the azimuth and elevation output from the sensors. While within an hour of solar noon, fine tune the alignment of the sensors so that both azimuth and elevation outputs are no more than 0,05° from zero and each sensor is no more than 0,05° of each other (for example, one monitor could show an azimuth output of –0,03° while the other is +0,02°). Typically, gross alignment of sensors is achieved based on a sunspot or a shadow alignment, but fine tuning shall be done while monitoring electrical output for both azimuth and elevation. High-accuracy alignment will typically require that each sensor is mounted to the tracker using a three-point spring-loaded adjustable configuration (two points if azimuth and elevation measurements are in separate devices). If mechanical adjustment does not provide the ability to achieve alignment within 0,05° of zero, then offsets can be applied through the data acquisition system or through an offset correction to the entire data set. Offsets shall be determined at the onset of testing and further drift between the two sensors shall be considered actual pointing error. Fifteen min of clear-sky data after completion of the alignment procedure shall be used to determine the offset to be applied to each sensor for the remainder of the data collection period. The 15 min of data from both sensors shall be plotted on the same graph and provided in the test report. The offsets shall be documented. The alignment period is specified around solar noon because it is acknowledged that the pointing vector of each monitor can separately change as the tracker flexes throughout the day or week. By aligning the sensors near solar noon, tracking-accuracy statistics are referenced to the time of day when the highest direct normal irradiance (DNI) is available.

7.4.2.3 Data recording parameters

Recorded data shall include:

- Tracker pointing error = $\sqrt{Azimuth_{error}{}^{2} + Elevation_{error}^{2}}$. The non-pertinent azimuth or elevation term shall be dropped for single-axis trackers
- Direct normal irradiance (DNI)
- Global normal irradiance (GNI)
- Wind speed
- Date and time

Tracker pointing error should be recorded in 1 min instantaneous increments.

Irradiance measurements should be recorded in 1 min average increments.

Wind speed data should be reported in 1 min increments for the 10 min mean speed at a 10 m height. Terrain for the wind measurement and tracker location shall have a slope of less than 3 %.

Data shall be recorded for a minimum of 5 days with a minimum DNI per day of 2 400 Wh/m^2 (e.g., at least 6 h of a DNI of 400 W/m^2 or greater).

The date and location of the test shall be reported to facilitate assessment of adequacy of the data collection, particularly with respect to range of motion.

7.4.3 Data binning by wind speed

The data are to be separated into a low wind-speed bin if less than or equal to the wind threshold of 4 m/s and separated into the high wind-speed bin if greater than 4 m/s.

Two bins represent a compromise to minimize test duration, complexity, and cost. The manufacturer may choose to report tracking-accuracy statistics for additional wind-speed bins and include relationship with wind direction.

7.4.4 Data filtering

7.4.4.1 General

All data filtering shall be documented within the tracking-accuracy test report.

7.4.4.2 Filter data for range of motion

If the tracker manufacturer specifies a maximum range of motion, remove all data that occurred during times when the sun was out of this specified range of motion.

7.4.4.3 Filter data for minimum irradiance (optional)

- Remove all data recorded when the DNI is less than 250 W/m^2.
- Remove all data recorded when the ratio of DNI to the GNI is less than 0,25.
- Opting out of irradiance filtering may be appropriate when specifying a tracker for non-concentration or low-concentration applications.

7.4.4.4 Other data filtering

If any additional filtering is performed on the data, this shall be specifically noted in the report. For example:

- “3 h of data were removed due to the observation of a leaf shading the sun sensor during this time.”
- “2 h of data were not recorded on one of the measurement days due to a failure in the datalogging system.”
- “30 min of data on one of the measurement days were discarded because of a tracker mechanical stall during that time.”

7.4.5 Data quantity

For each of the four data sets (“low wind, min deflection measurement,” “high wind, maximum deflection measurement,” and so on), ensure there are a sufficient number of data points.

The data from each pointing error sensor shall satisfy these criteria:

- At least 360 data points after the above filtering
- Data from at least 5 separate days, with at least 50 data points per day
- Number of points at high wind speed (180)
- At least 50 data points before noon and 50 points after noon.

7.4.6 Accuracy calculations

For each of the data sets, calculate the following two values:

Typical accuracy: the median value of the pointing error over the filtered data set. All recorded pointing-error values will be positive values; therefore, the “typical accuracy” will be a value greater than zero but less than the 95th percentile accuracy.

95th percentile accuracy: the 95th percentile value of the pointing error over the filtered data set. That is, 95 % of the measured data points fall below this error.

As a cautionary note, 95th percentile accuracy in no way implies that the tracking-accuracy statistics follow rules for a normal distribution. Figure 17 presents a histogram of the frequency of the pointing error over the entire test period. In this case, it is clear that distribution is not normal. For this data set, the typical accuracy is about 0,65° and the 95th percentile accuracy is about 0,97°.

These calculated accuracy values may be tabulated as shown in Table 2 below. The average wind speeds for the "low wind" and "high wind" bins shall be reported as shown.

Table 2 – Alternate tracking-accuracy reporting template

	Low wind*		**High wind****	
	Typical accuracy	**95th percentile accuracy**	**Typical accuracy**	**95th percentile accuracy**
Min deflect point	0,4	0,8	0,5	1,0
Max deflect point	0,7	1,2	0,8	1,4

* Low wind = wind speed < 4 m/s (measured mean = **2,6 m/s**).

** High wind = wind speed > 4 m/s (measured mean = **6,3 m/s**).

8 Tracker test procedures

8.1 Visual inspection

8.1.1 Purpose

The purpose of this test is to detect any visual defects from the component level to the entire tracker structure. Visual inspection is performed before and after all other testing and serves to detect and document a wide range of unknown problems that could arise due to the performed tests. Unless specified in the requirements for a given test, visual defects do not constitute failures.

8.1.2 Procedure

Carefully inspect each component and the entire tracker for the following conditions. Document all defects found in written and photographic form.

- Broken, cracked, bent, or misaligned parts, external surfaces, or structural components.
- Visual corrosion on electrical connectors, interconnections, or bus bars.
- Visual corrosion of enclosure surfaces.
- Visual corrosion of screws, nuts, and washers.
- Loose screws, bolts, nuts, or grommets.
- Cracked, frayed, or otherwise damaged wire or cable.
- Faulty terminals, or exposed energized electrical parts.
- Any other conditions that might affect functioning, performance, or safety.

Make notes of any visual conditions that worsen or change over the course of testing. Loose screws, bolts, and nuts shall be tightened according to manufacturer installation instructions.

8.1.3 Requirements

To pass the initial visual inspection, there shall be no defects that present safety issues or impact actuation abilities per the following list:

- Pooled water on live parts or windings not designed to operate when wet.

- Faulty or loose terminals.
- Exposed energized electrical parts or current carrying conductors.
- Cracks that impair sound structural functioning or present potential harm to persons working around the tracker.

All other potential safety issues shall be documented in the test report but are not considered grounds for failure.

8.2 Functional validation tests

8.2.1 Purpose

The purpose of functional validation testing is to ensure that the tracker meets the basic design specifications identified in the specification template by the manufacturer. Although a wide range of functional validation tests are identified, some of the tests are not required if that function is not claimed for the specific tracker under test. Unless otherwise specified, results of functional tests depend on the combination of mechanical components and the electronic control system. If any of the above components change as part of a design iteration, then the functional tests shall be repeated to be considered in compliance with this standard.

8.2.2 Tracking limits verification

The tracker shall be installed according to 7.4.2.1. The tracker shall be commanded or otherwise driven to the limits of tracking for both extremes of each its axes. It shall be verified that motion automatically stops at the expected limits and the limits shall be recorded in degrees.

8.2.3 Hard limit switch operation

This test is only applicable to systems that make use of a hard limit switch. The tracker shall be installed according to 7.4.2.1. The tracker shall be driven beyond each of the normal tracking limits such that it triggers each hard limit switch. The manufacturer shall specify the desired means to power the drive system beyond the normal tracking limits. It shall be verified that upon contact with each hard limit switch that motion stops and that the drive-system power-supply circuit has been opened. It shall be verified that no damage has occurred to the tracker system.

8.2.4 Automatic sun tracking after power outage and feedback sensor shadowing

The tracker shall be installed according to 7.4.2.1. The tracker shall be in its automatic sun-tracking mode and it shall be verified that pointing error is less than the reported “low-wind 95th percentile accuracy.” All power shall be disrupted to the tracker controller and to the tracker drive system (with exception to permanent manufacturer built-in battery backup) for a period of at least 1 h. After an hour has passed, power shall be restored to the tracker system. It shall be verified that the tracker returns to on-sun tracking within the reported “low-wind 95th percentile accuracy” and with no human intervention. The tracker does not immediately have to return to an on-sun position but can go through auto-calibration. The time it takes, from power restoration to the return to on-sun tracking, shall be reported. This test shall be conducted within 2 h of solar noon and the sun shall be clearly visible from the time power is restored until the tracker achieves on-sun status.

If the tracker controller employs active feedback from a sun-position sensor, the above test shall be repeated; but rather than disrupting power, the sun-position sensor shall be shadowed from the sun for 1 h. The time it takes, from removal of shadowing to the return to on-sun tracking, shall be reported. This test shall be conducted within 2 h of solar noon and the sun shall be clearly visible from the time shadowing is removed until the tracker achieves on-sun status.

8.2.5 Manual operation

This test is only applicable to trackers that include a manual operation mode. The tracker shall be installed according to 7.4.2.1. Manual control shall be tested to verify that the operator can drive both axes in both directions. It shall also be verified that when the tracker is in automatic sun-tracking mode that manual controls override the automatic control.

8.2.6 Emergency stop

This test is only applicable to trackers that include an emergency-stop option. The tracker shall be installed according to 7.4.2.1. It shall be verified when the emergency-stop function is engaged that the tracker motion stops within 1 s and that the drive-system power-supply circuit has been mechanically opened. Vibrational motion from wind or another outside forces is acceptable.

8.2.7 Maintenance mode

This test is only applicable to trackers that include a maintenance-mode option. The tracker shall be installed according to 7.4.2.1. Maintenance mode shall be engaged and its position verified. It shall also be verified that the tracker drive-system power-supply circuit has been opened while in maintenance mode.

8.2.8 Operational temperature range

The operational temperature range will not be validated for outdoor conditions due to costs and challenges associated with such a test. In place of this validation, operation of the drive train and control electronics shall be confirmed at the maximum and minimum operational temperatures stated in the manufacturer’s specification sheet. This test will be conducted per 8.5, accelerated environmental testing. Testing per 8.5 does not include a full payload, a payload support structure, or other outside loading factors and therefore is only a limited validation of the operational temperature range.

8.2.9 Wind stow

This test is only applicable to trackers that include a wind-stow option. The tracker shall be installed according to 7.4.2.1. A wind sensor or appropriate input signal shall be connected to the tracker control system as specified by the manufacturer. If a wind sensor is used, a fan or other means can be used to exceed the wind speed that triggers stow. It shall be verified that when the specified wind speed is exceeded via the wind sensor or input signal the tracker moves to the stow position. The degrees of the actual stow position shall be measured and reported.

8.3 Performance tests

8.3.1 Purpose

The purpose of performance testing is to quantify tracker energy consumption and the time it takes to stow. Unless otherwise specified, results of performance tests depend on the combination of mechanical components and the electronic control system. If any of the above components change as part of a design iteration, then the performance tests shall be repeated to be considered in compliance with this standard.

8.3.2 Daily energy and peak power consumption

The tracker shall be installed according to 7.4.2.1. In conjunction with the tracking accuracy tests described in Clause 7, the power-supply circuit to the tracker shall be instrumented with an energy and power transducer (accuracy shall be 1 % or better). Energy-usage measurements shall be recorded at least every 5 min for the entire period of the tracker accuracy test. To detect the peak power consumption the power measurement shall be sampled at frequency of 1 Hz or faster.

The measurements shall be binned into active tracking and non-tracking. The recorded energy measurements will then be averaged to determine the average hourly energy consumption for both active tracking and non-tracking. These values will both be multiplied by 12. The 12 h active-tracking energy consumption and 12 h non-tracking energy consumption will be reported.

The recorded power measurements shall be binned into active tracking and non-tracking. The effective peak power consumption shall be determined for both bins. In case an AC power supply is used the peak apparent power consumptions in both bins shall also be reported.

The average wind speed (per 7.4.2.3), test dates, and latitude shall be attached to the reported energy and power consumption values.

8.3.3 Stow time and stow energy and power consumption

The tracker shall be installed according to 7.4.2.1. The tracker shall be placed in its farthest functional position from the manufacturer-indicated stow position. The power-supply circuit to the tracker shall be instrumented with an energy-usage transducer (accuracy shall be 1 % or better). The wind speed shall be measured (per 7.4.2.3) during this test. The tracker shall be triggered to move to stow position at the same moment that time and energy usage and power measurements are initiated. Both the time required and the energy usage shall be reported for the movement period to the stow position. Also the peak power and if applicable the peak apparent power shall be recorded.

The average wind speed during the movement to stow shall be reported in conjunction with stow time, stow energy consumption, and peak power consumption.

It is recommended that the measurement per 8.3.3 be repeated when the tracker is under loading associated with high winds. Trackers are often installed with battery backup power to ensure that stow can be achieved even when grid power is lost. Testing stow time and stow energy consumption with no load is not sufficient to determine if a battery backup system is sized appropriately. If the measurement per 8.3.3 is repeated under load, the loading shall be determined based on formula (2) per 8.4.4.2, where multiple options are provided for determining the dimensionless moment coefficient, C_M. The maximum torque to be applied to the given axis of rotation shall be calculated using 1,1 times the wind speed that triggers stow. Due to the wide range of tracker designs, the manufacturer shall determine how to apply such loading. One possibility is that the tracker is going to move from the vertical position to the horizontal position and, in this instance, weights can be attached to the lower end of the tracker while in the vertical position. Although the torque will vary as the axis rotates, this is a simple and low-cost means to apply the loading.

8.4 Mechanical testing

8.4.1 Purpose

This subclause describes measurement of the repeatability of the drive system, the deflection under applied forces and moments, backlash, and mechanical drift, and provides an indication of the tracker’s ability to operate or survive in specified wind and other loading conditions. Note that these measurements are separate from the accuracy measurement above: the accuracy measurement characterizes the entire system in real-world conditions, including structure, electronics, algorithms, and sensors. The following tests characterize isolated mechanical aspects of the tracker. Due to the isolated nature of some of the mechanical tests, not all design iterations require retests to be compliant with this standard. See the individual test to determine if retest is required.

8.4.2 Control/drive train pointing repeatability test

8.4.2.1 Purpose

Control/drive train pointing repeatability is an optional test in lieu of tracking-accuracy testing after mechanical loading. It is assumed that this test may not be appropriate for some controllers that use pure closed-loop control. The purpose of this test is to measure the repeatability of the tracker control system and drive mechanism by pointing a fixed vector in relation to the tracking plane at a desired location. Stable pointing repeatability both before and after load testing also serves as an indication that the tracker survived the specified testing. If the tracker controller does not provide the option to be moved to at least one commanded suitable location (e.g., many closed-loop controllers do not have this option), not including limit positions, then tracking-accuracy calculations shall be completed according to 7.4 both before and after mechanical load testing in lieu of pointing repeatability testing. Tracking-accuracy testing after mechanical loading can be limited to just the array maximum deflection point and the low wind condition. Pointing-repeatability testing is preferred to tracking-accuracy testing (for verification of survival to mechanical loading) because it takes much less time to perform and does not depend on sun availability. For these reasons, it is assumed that pointing repeatability may be less expensive to complete, and it may be in the manufacturer's interest to incorporate an option within its controller software to point or stop the tracker at a suitable location. Control/drive train pointing repeatability depends on the combination of mechanical components and the electronic control system. If any of the above components change as part of a design iteration and control/drive train pointing repeatability is opted for, then it shall be repeated to be considered in compliance with this standard.

8.4.2.2 Procedure

The tracker shall be installed according to 7.4.2.1. A laser or other appropriate devices will be installed within 1,5 m of the center of the tracking plane. The laser can be oriented at any direction relative to the tracker plane that is convenient to locating a target. The tracker shall be commanded to the position that will be used for pointing-repeatability testing. A target for the laser beam shall be installed at a distance from the laser such that pointing accuracy can be measured to the lesser of (manufacturer-stated tracking accuracy)/3 or 0,02°. The target shall be positioned so that it does not interfere with the tracker's full range of motion. The target and/or laser shall be adjusted so that the laser initially points to the center of the target within 0,02°. The target and the laser shall then be locked into position such that wind speeds below 4 m/s and normal tracker movements do not interfere with the 0,02° measurement accuracy.

The tracker shall be moved at least 5° for both axes of movement in both rotational directions and then moved back to the commanded test position. Upon returning to the commanded test position, the laser point location on the target shall be recorded. This process shall be repeated five times. "Control/drive train pointing repeatability" shall be reported for both axes of motion and is the maximum magnitude, in degrees, between all test runs for the given axis. For single-axis trackers, only the single axis is considered.

8.4.2.3 Requirements

Pointing-repeatability testing shall be completed both before and after 8.4.3 and 8.4.5 have been completed. 8.4.3 and 8.4.5 can be completed in sequence so that only one before and one after test is required. As stated above, if the tracker controller does not provide the option to be moved to at least one commanded location, not including limit positions, then tracking accuracy calculations can be completed in lieu of pointing repeatability. Tracking-accuracy testing after mechanical loading can be limited to just the array maximum deflection point and the low wind condition. Pointing-repeatability testing is preferred to tracking-accuracy testing (for verification of survival to mechanical loading) because it takes much less time to perform and does not depend on sun availability.

Reported pointing repeatability, both before and after mechanical loading, shall be within 10 % in order to pass. Before and after measurements shall be fully documented in the test report.

If tracking accuracy is used in lieu of pointing repeatability, reported 95th percentile accuracy for the array maximum deflection point, both before and after mechanical loading, shall be within 20 % in order to pass.

8.4.3 Deflection under static load test

8.4.3.1 Purpose

This test is considered optional. This test serves to measure tracker structural deflection under a minimum of two different static loading conditions. The loading conditions specified are considered light relative to the wind or snow loading that a tracker may see in its operational environment. The loads tested hereinafter are not intended to induce permanent structural deformation. The purpose of this test is to capture gross design problems and to provide third-party measurements that enable validation of finite-element structure models conceived for the given tracker. Validated models can then be used to predict performance or survival in various environmental conditions such as wind, snow, or ice. Deflection under static load only depends on the structural/mechanical components of the tracker system and therefore shall be repeated only if opted for and if said components are modified as part of a design iteration.

8.4.3.2 Procedure

The tracker shall be installed according to the manufacturer recommendations. The tracker may be tested with or without a payload as is desirable by the manufacturer. Payload weight, center of mass, and number of units shall be documented in the test results, and a photograph of the test setup shall be included. In the event that a tracker is only designed for one specific module architecture, it may be desirable to complete this test with those specific modules whereas a tracker that accepts a wide range of modules is likely to be tested with only its payload support structure. A minimum of eight deflection sensors (the accuracy of the sensors shall be reported in context of the maximum and minimum deflections measured) shall be mounted to tracker structural components. The type location of the sensors shall be chosen by identifying the regions where deflection under load is most likely to occur and the most appropriate sensor for that location. Figure 5 is an illustrative case. The tracker shown in Figure 5 is a single pole mount for illustrative simplicity, but the basic measurement locations should apply to the nearest structural locations behind the plane of the payload for any tracker type. For example, locations 1, 3, 4, and 6 should be the corners or four symmetric outer-perimeter locations on the payload support structure. Locations 2, 8, 7, and 5 should be equally spaced along the main structural support axis or axes for the payload. If the tracker structure is symmetrical in all ways (as in Figure 5), then the minimum number of deflection sensors can be reduced from eight to four. In this example, the deflection measurements at locations 4, 5, 6, and 8 could be avoided because the results should be nearly identical to locations 1, 2, 3, and 7. With sensors in place, structural deflection is to be measured for four different load configurations (see Figure 6 and Figure 7) and two load levels. All load configurations in Figure 6 represent the tracker payload in the horizontal orientation, whereas Figure 7 represents the payload in a vertical orientation. If the tracker cannot fully achieve horizontal or vertical position, the actual payload structure shall be oriented as close to horizontal or vertical as possible. The achieved orientation shall be documented in the test report. All loadings depicted in Figure 6 and Figure 7 correspond to point loading on structural components and are pictures given for simplicity. The tracker in Figure 6 depicts four structural ribs, although a tracker could have any number of ribs, and point loading is expected to be adjusted accordingly.

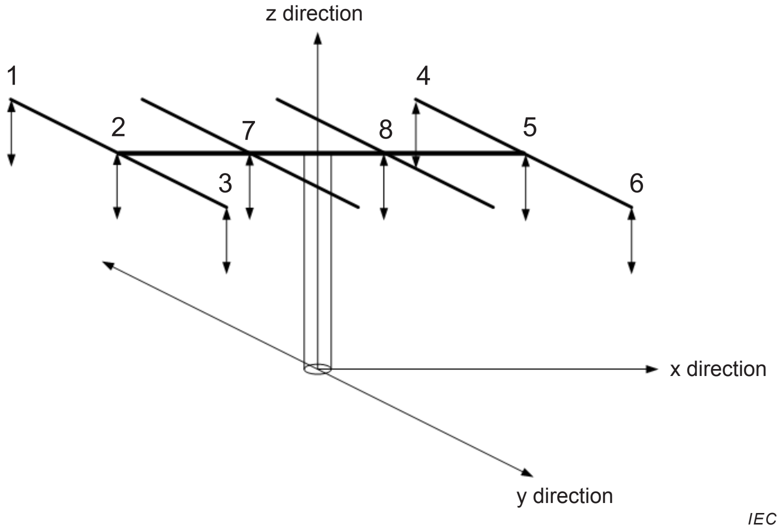


Figure 5 – Example measurement locations for structural deflection

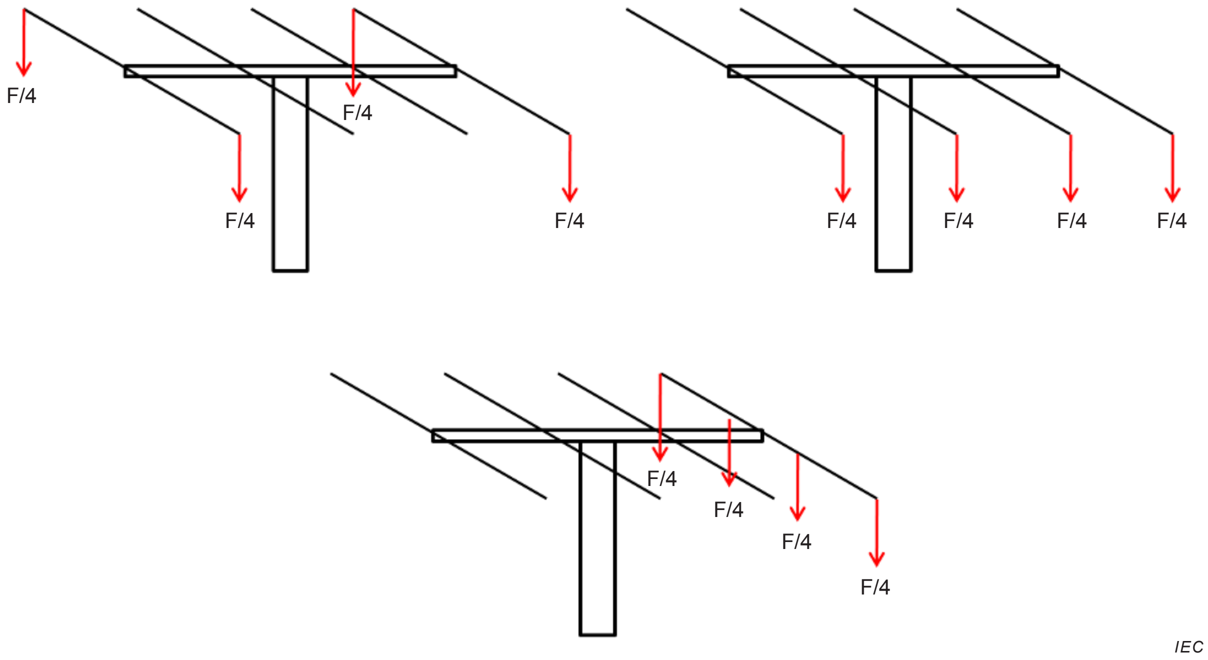


Figure 6 – Load configurations while the payload is in the horizontal position

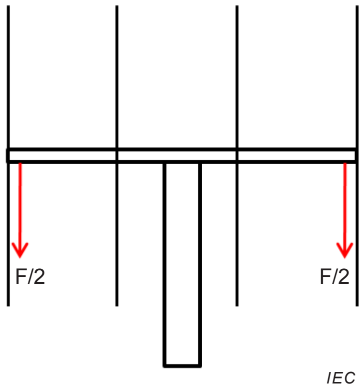


Figure 7 – Load configuration when the payload is in the vertical position

Regardless of tracker type, the point loading shall be equally spaced and fully documented in the test report. The two load levels to be tested are F = (20 Pa) × (nominal payload surface area in m^2) and F = (100 Pa) × (nominal payload surface area in m^2). The specified load levels are intended to provide measureable deflection that is not permanent or damaging to the tracker. Although the above-specified load levels are considered light, they are not evenly distributed over the entire payload support structure. For this reason, the tracker manufacturer can request load levels that are appropriate for a specific design. All load levels and locations shall be documented in the test report.

All deflection measurements shall be repeated at least three times. Measurements for all repeats shall be reported for all deflection points for each of the load levels and load configurations. Caution should be taken to avoid taking measurements under wind speeds that influence the deflection measurements.

8.4.3.3 Requirements

If this test is included, the following is required: photos and diagrams shall fully document the locations of all deflection sensors and all point loads applied. A table shall document the maximum, minimum, and average deflections for all load levels and load configurations. The accuracy of the deflection sensors shall be reported. The maximum wind speed shall be reported for the period in time that measurements are being taken. The tracker is considered to pass if the following are true:

a) Deflection measurements both before and after loading is removed shall agree within 5 % for each measurement location.

b) The tracker passes 8.4.2.3 after this loading test is completed.

8.4.4 Torsional stiffness, mechanical drift, drive torque, and backlash testing

8.4.4.1 Purpose

The purpose of torsional stiffness testing is to measure angular deflection versus applied torque for each drive axis of the tracker. The maximum applied torque is calculated to simulate operational conditions that arise due to wind loading. Testing at the maximum applied torque with the driving mechanism both on and off serves to verify that the drive train does not backtrack/drift and that drive torque is sufficient to move the tracker under wind loading. The torque is applied at a fixed rate from zero to the maximum and therefore information is provided about backlash as a consequence of the test. Torsional stiffness, mechanical drift, drive torque, and backlash testing is considered dependent on the components comprising the drive train and not the electronic control system. If any of the drive train components change as part of a design iteration, then the following tests shall be repeated to be considered in compliance with this standard. The following tests shall be considered optional for ganged trackers because the tests were not designed to be applied to systems with this complexity. Alternatively, it is recommended that the manufacturer of a ganged system provide the test lab a plan for measuring torsional stiffness, mechanical drift, drive torque, and backlash. This alternative testing shall be documented in the test report in the event that it is used.

8.4.4.2 Procedure

This test is designed to only test the torsional stiffness of the drive train and therefore testing can be performed isolated of the tracker payload and foundation (i.e., testing can be performed indoors or outdoors). The drive train shall be mounted in a fashion such that a moment can be applied to both axes of operation. Appropriate sensors that can measure angular displacement (the accuracy of the sensors shall be reported in context of the maximum and minimum angular displacement measured) shall be mounted to each axis of rotation on the drive train.

A moment loading, near a net force equalling zero, shall be applied to each drive axis ramping from a 0 N·m torque to the maximum calculated torque at a uniform rate over the course of one minute. Once the maximum load is achieved, the torque shall then be decreased at the same rate to zero and then the test shall repeated in the reversed rotational direction. This cycle shall then be repeated at least three times, with measurements taken of torque and angular displacement in increments of 10 % of the maximum torque. Figure 8 presents an example of a moment load applied to an elevation axis.

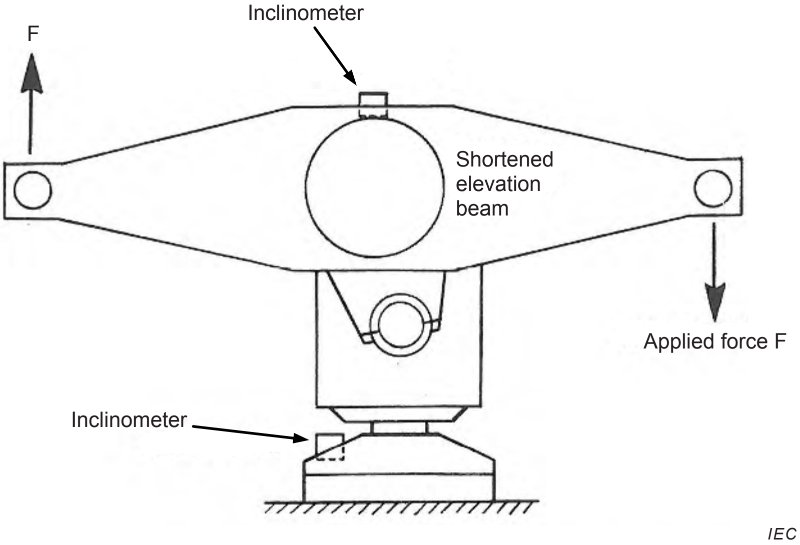


Figure 8 – Moment load applied to an elevation axis

Peak torques exerted on tracker axes are likely to be the result of wind loading, and therefore this test shall be completed for three separate maximum torques corresponding to three wind loading conditions. Those conditions are 10 m/s, the stow wind speed per the manufacturer's specification sheet, and 1,1 times the specified stow wind speed. The 1,1 factor is considered because the tracker may encounter increased wind gusts as it travels to the stow position. If the tracker does not have a stow position then maximum specified operational wind speed shall be used in lieu of the wind speed that triggers stow. If a maximum operational wind speed is not provided in the specification sheet, then 40 m/s shall be used in lieu of the stow wind speed. Figure 9 represents an idealized plot of angular displacement versus applied torque for the basic operational wind loading.

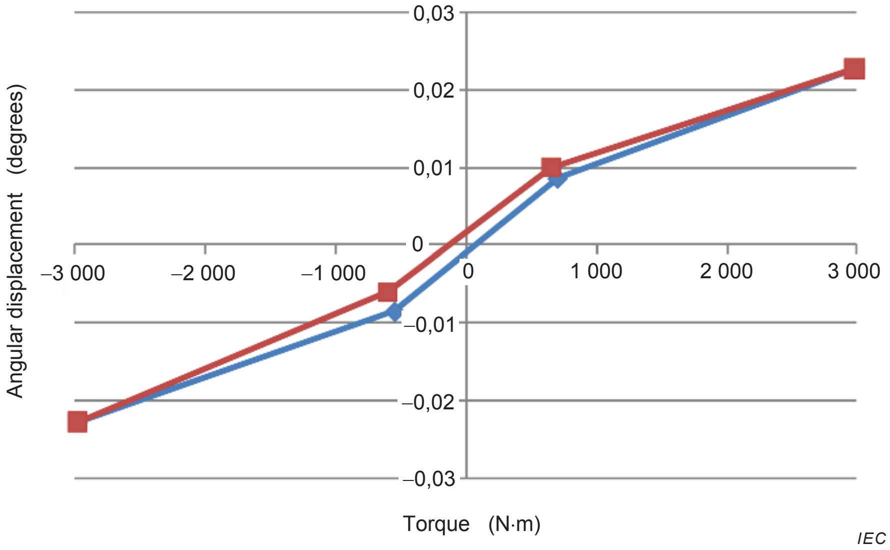


Figure 9 – Angular displacement versus applied torque to axis of rotation

Figure 9 is included to demonstrate two points in regards to measuring angular displacement versus applied torque. First, there will typically be some hysteresis from ramping up the torque to ramping down the torque. Second, the plot will often show a distinct change in slope as the torque increases from very low levels to a moderate level, which indicates backlash. In this example, the slope changes at about ± 0,01°, and therefore, the backlash would be reported as ± 0,01°. If there is a clear transition in slope, as in Figure 9, the backlash of the drive train shall be calculated by averaging the magnitudes of the angular displacements at the points where the slopes change for the three repeats with the torque corresponding to 10 m/s winds. In the case where the slope changes gradually, the backlash shall be calculated by averaging the magnitudes of the displacements for a torque that is equal to ± 20 % of the maximum torque corresponding to 10 m/s winds. If there is a significant deviation between backlash in each rotational direction, the backlash can be reported separately for each rotational direction. In the case where there is no transition in slope from maximum negative to maximum positive applied torque, the backlash shall be noted as undetectable.

The maximum torque to be applied corresponding to each wind speed shall be calculated using formula (2).

$$\text{Torque}\left(N\cdot m\right)=0{,}5\,C_{\mathrm{M}}\rho V_{\mathrm{test}}^{2}A_{\mathrm{ref}}L \tag{2}$$

where C_M is the dimensionless moment coefficient, ρ is the density of air (assumed to be 1,225 kg/m^3), V_{test} is wind speed at the axis of rotation calculated using formula (1) (see 6.12.3), A_{ref} is the maximum area in m^2 of the payload, and L is the characteristic length of the payload structure, which corresponds to the applied moment. Figure 10 (a) shows a side view of a tracker and the characteristic length for an elevation torque, and Figure 10(b) shows a tracker from above and the characteristic length for an azimuth torque. The manufacturer is provided options a), b), and c) below for determining C_M for formula (2). Regardless of the option that is implemented, the test report shall document the resulting torques that are applied to each axis of the tracker, the reference area, and the characteristic length. Option a) is considered superior to option b) and option b) superior to option c). If options a) or b) are implemented, third-party data shall demonstrate that the tracker was tested in increments through its full elevation rotational range and a 90° azimuthal range (head-on at one extreme and a side view at the other extreme). Assuming the tracker has a horizontal stow position, the stow moment coefficient derived from third-party wind tunnel or field test data shall be for the tracker in a position 10° from horizontal. This deviation from horizontal accounts for the fact that wind deviates from horizontal flows in the real world. Deriving the stow moment coefficient can be done using an interpolation method if the actual wind tunnel or field data were not collected specifically at 10° but instead was collected at multiple angles encompassing 10°.

Option a): A third-party wind tunnel laboratory can derive torque coefficients from wind tunnel pressure data on a scale model of the tracker.

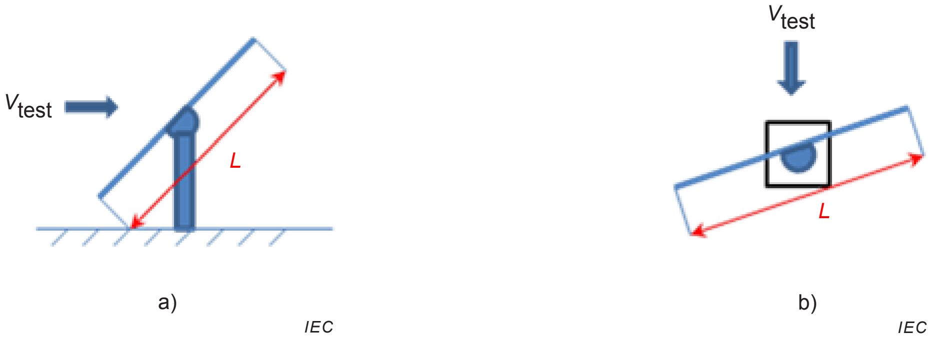
Option b): A third-party engineering firm can derive torque coefficients from field data based on pressure measurements at an array of locations on the tracker payload surface. Pressure data shall be measured at a frequency of 10 Hz or faster to be considered valid for deriving said coefficients. For example, third-party computational fluid dynamics (CFD) modelling could be validated by field pressure data and be used to generate C_M.

Option c): In the event that no third-party testing is done, the following minimums shall apply to C_M:

C_M no less than 0,25 for varying tracker positions (applies to 8.4.4.2), (also applies to 8.4.5.2 if the tracker does not have a horizontal stow capability)

C_M no less than 0,08 for a tracker in a horizontal stow position (applies to 8.4.5.2).

c_M values of 0,5 or higher are recommended for procedure 8.4.4.2 and c_M values of 0,15 or higher for procedure 8.4.5.1 for trackers that have not been through third-party wind load analysis. Wind tunnel testing indicates that peak values of c_M can be as high as 0,6 for elevation axis torque and 0,7 for azimuth axis torque as applied to single-unit trackers with a square payload area. Because this standard applies to a wide range of trackers, it is expected that c_M will often be significantly less than 0,7 due to optimizations in tracker design that are implemented to reduce wind loading. Factors such as payload profile, tracker height, multiple trackers in a field, payload porosity, and intentional components to disrupt the wind are just some of the items that can reduce c_M. For example, c_M can be a factor of 10 less for ganged trackers because the wind speed on perimeter trackers can be grossly different than on interior trackers, although they are all on a ganged drive system.



a) b)

Figure 10 – Examples of characteristic length for (a) elevation torque, (b) azimuth torque

"Absence of mechanical drift" and "sufficient drive system torque" shall be validated under the maximum torque calculated for 1,1 times the wind speed that triggers stow per formula (2). After ramping to this torque, the loading force shall be held constant. The angular displacement shall be measured for at least 1 min under this load. If the angular displacement varies no more than 10 % while under this fixed load, it can be stated that the drive train does not mechanically drift. While continuing to maintain the fixed torque, the axis under test shall be engaged against the applied torque to move under its normal driving mechanism. If the axis rotates at a rate of at least 50 % of its nominal speed without stopping for a monitoring period of 30 s, then the driving mechanism passes as having sufficient torque to operate under designed wind loading.

8.4.4.3 Requirements

Photos and diagrams shall fully document the locations of all deflection sensors and loading points. The accuracies of the equipment used and documentation regarding the loading apparatus shall be included in the test report. The test report shall include plots of angular displacement versus applied torque for the three loading conditions calculated based on the specified wind speeds. The drive train is considered to pass if the following are true:

a) Angular displacement measurements both before and after loading are completed (but prior to engaging the drive train) shall agree within 5 % for each measurement location.

b) No mechanical drift shall be measured.

c) The drive mechanism shall be able to rotate the axis as specified under the applied torque.

8.4.5 Moment testing under extreme wind loading

8.4.5.1 Purpose

Trackers that are going to be able to survive in the field for 20-plus years justify structural design that can tolerate 40 m/s wind speeds (or the maximum survival wind speed specified by the manufacturer). Because most manufacturers place the tracker in a stow position for such conditions, this test is primarily designed to examine survival of extreme winds in the stow position. If the tracker has already been instrumented with deflection sensors per 8.4.3, then deflection measurements shall be recorded during this test to provide additional data for structural model validation. Moment testing under extreme wind loading is considered dependent on the components comprising the drive train and not the electronic control system. If any of the drive train components change as part of a design iteration, then the following test shall be repeated to be considered in compliance with this standard. The following test shall be considered optional for ganged trackers because the test was not designed to be applied to systems with this complexity. Alternatively, it is recommended that the manufacturer of a ganged system provide the test lab a plan for moment testing under extreme wind loading. This alternative testing shall be documented in the test report in the event that it is used.

8.4.5.2 Procedure

The tracker shall be installed according to 7.4.2.1. If the manufacturer opted in for 8.4.3, then additional deflection measurements shall be measured and reported accordingly. The tracker shall be subjected to moment loading in the two configurations shown in Figure 11.

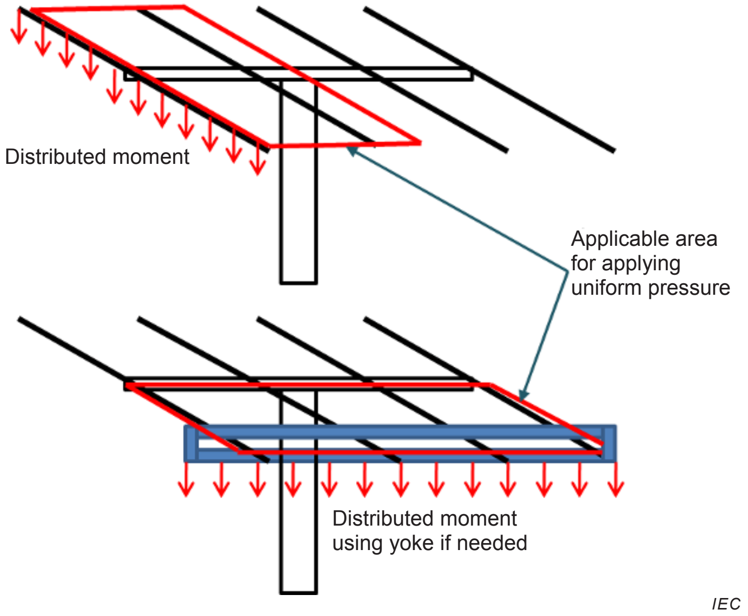


Figure 11 – Two configurations for extreme wind moment loading

Figure 11 represents the payload in the horizontal position or the nearest position to horizontal that the tracker can achieve. The calculated moment load shall be evenly distributed and shall directly transfer to the payload support structure. The distributed moment can be applied via a uniform pressure or uniform loading, although pressure is the recommended approach. The moment load tested shall correspond to a 40 m/s wind speed (or the maximum survival wind speed specified by the manufacturer).

Formula (2) shall be used to calculate the moment approximating a 40 m/s wind speed (see 8.4.4.2). For the stow position, the wind angle of attack will be assumed to be minimized and therefore C_M is expected to be reduced from the testing performed in procedure 8.4.4.2. It is assumed that in the stow position moment, testing is only applicable to the elevation axis of rotation. If the tracker under test does not have a stow position, then C_M shall be consistent with values used in procedure 8.4.4.2 and both axes of rotation shall be tested, because the tracker could be in any position when extreme winds occur. Reporting requirements per procedure 8.4.4.2 shall be followed.

The tracker shall be loaded and unloaded at least three times for both configurations and for both load levels. The maximum, minimum, and average deflection value shall be reported.

8.4.5.3 Requirements

If 8.4.3 was opted for, photos and diagrams shall fully document the locations of all deflection sensors and the location/application of each moment loading. A table shall document the maximum, minimum, and average deflections for all load levels and load configurations. The accuracy of the deflection sensors shall be reported. The maximum wind speed shall be reported for the period of time that measurements are being taken. The tracker is considered to pass if the following are true:

a) Deflection measurements both before and after loading is completed shall agree within 5 % for each measurement location.

b) The tracker passes 8.4.2.3 after this loading test is completed.

8.5 Environmental testing

8.5.1 Purpose

The overall objective of this testing is to attempt to induce failures or infant mortality associated with design that may occur as a result of accelerated environmental cycling of the drive system, control system, and associated wiring in a wide range of environmental conditions. Because the following tests depend on the interaction between the drive system and the control system, design iterations that alter any of the above components would require retest to be in compliance with this standard.

8.5.2 Procedure

A fully functional drive train (with control electronics within a standard deployment enclosure) shall be mounted for operation in an environmental chamber. The system does not require a payload interface or a full-size foundation interface; therefore, a representative assembly can be used in the chamber. For example, mounting pedestals and torque tubes can be shortened to reduce chamber space needs, but gear drives, hydraulic pistons, motors, and other drive train equipment shall be full size. The manufacturer shall provide means for the test lab to mount the drive train in the environmental chamber. The test setup shall include standard wiring for drive train control and a mock-up of payload wiring that will typically cross through or around the drive train. Mock-up wiring is included to detect failures that occur when limit switches or other controls fail and the tracker rotates further than intended by design. Once the drive train and controls have been installed, photos shall be taken and a visual inspection shall be completed.

A typical duty cycle shall be repeatedly applied to the drive train while under environmental cycling and within the manufacturer-specified operational temperature range. The test lab shall monitor the drive train with cameras or other suitable equipment to verify that the duty cycle is occurring while the test is in progress. A typical duty cycle shall move each applicable axis of rotation through its full range of motion used in tracking the sun. The duty cycle is intended to mimic normal on-sun movements for the given tracker. Each applicable axis shall move at a minimum average rate of at least 0,005° per second, but not faster than a maximum average rate of 0,015° per second. There is no limit on the speed achieved when returning to the beginning of the duty cycle/beginning of day position. For controllers with closed-loop control, it may be necessary to replace feedback from a sun sensor with a mock signal to the controller. In a case such as this, the test report shall document that said feedback sensor was not part of the environmental testing. The manufacturer shall provide means to repeatedly apply the duty cycle while in the environmental chamber and may also provide means to cease operation when key device surface temperatures are outside the operation temperature range listed on the specification sheet. The manufacturer shall specify which surface temperatures will determine switching the duty cycle on and off. Surface temperatures are used rather than chamber temperatures because drive trains with large thermal masses will have a significant lag behind chamber air temperature. The drive train is not required to be under any specific load while going through chamber testing. The duty cycle profile, surface temperature locations, and operational temperatures shall be documented in the test report.

Prior to beginning the environmental testing, each axis of rotation shall be loaded to the maximum specified payload. Maximum specified payload does not include wind loading or other external loading that may occur in the outdoor environment, but rather, is the dead load associated with the normal payload interface and the payload itself (i.e., weight of structural framing combined with modules, mirrors). The maximum specified payload can be applied as a separate torque to each axis of rotation through any suitable method. It is not intended that an actual payload structure be attached to the drive train under test unless this is the most economical means to test the drive train under load. For example, a lever arm could be attached to the elevation axis and weights applied per manufacturer’s recommendations. The energy usage (accuracy shall be 1 % or better) and time required to complete a duty cycle shall be measured while under this load prior to initiating environmental cycling. These same measurements will be completed after environmental testing is complete.

The operational drive train will be subjected to the following environmental testing on a single sample in the following order:

a) Temperature cycle with dust (no humidity added to the air): at least 40 cycles and 480 h shall be completed. The maximum temperature shall be 55 °C and the minimum temperature shall be –20 °C. If the operational temperature range specified in Table 1 (see 6.12.1) indicates the tracker can operate outside –20 °C to 55 °C, then the temperature range of this test shall be expanded to coincide with the specified values. In other words, –20 °C to 55 °C can be considered the minimum test conditions, but more extreme values shall be applied to align with the specification sheet. The cycle shall dwell for at least 5 min, but not more than 15 min, at ± 3 °C of the maximum and minimum temperatures per average surface temperature measurements at three distinct points on the drive train. The temperature measurement points shall be documented and have justification supporting that surface measurements are on an object with significant thermal mass in relation to the system under test. For the first 240 h, dust shall be circulated around the dynamic mechanical interfaces of the drive train. A4 dust per ISO 1203-1 shall be used (contains distribution of both fine and coarse particles). A temporary structure can be used to contain the region of circulating dust, as opposed to circulating dust in the entire environmental chamber. A blower or other mechanism shall be used to ensure that dust is circulating in the air. Because dust will settle and collect on surfaces, it may be necessary to periodically add additional dust to the blower system through the course of the 240 h. Video, photographs, or other methods shall document that dust is visible in the air at 10 min intervals throughout the test. An alternate option is to complete the 240 h of dust testing at a steady temperature before onset of the 480 h of temperature cycling. The combination of the dust and temperature cycling is recommended because it shortens test time and because temperature cycles can cause expansion and contraction of seals and other parts that may enhance the ability for dust to penetrate into places that can ultimately lead to failure. The alternate option is provided because facilities may not be readily available that can combine both tests or such a test could be prohibitively expensive.
b) Upon completion of temperature cycling, the specified operational temperatures shall be validated (8.2.8). Drive train movement shall be temporarily halted. The chamber shall be held at the minimum specified operational temperature until the surface of the drive train reaches said temperature. The minimum operational temperature shall be held for an additional hour. At this point, the drive train duty cycle shall be engaged. Visual confirmation shall be made that the tracker moves as expected over a 5 min period. If the drive fails to move after 30 s, then the attempt can be halted to avoid damage. The above procedure shall be repeated for the maximum specified operational temperature.
c) Humidity freeze cycling: 10 cycles and 240 h shall be completed. A cycle will consist of alternating from the damp heat (85 % relative humidity and 55 °C) to the minimum temperature condition (–20 °C). If the operational temperature range specified in Table 1 (see 6.12.1) indicates that the tracker can operate outside –20 °C to 55 °C, then the temperature range of this test shall be expanded to coincide with the specified values. In other words, –20 °C to 55 °C can be considered the minimum test conditions, but more extreme values shall be applied to align with the specification sheet. The cycle shall dwell for at least 5 min at ± 3 °C of the maximum and minimum temperatures per average surface temperature measurements at three distinct points on the drive train. The

temperature measurement points shall be documented and have justification supporting that surface measurement is on an object with significant thermal mass in relation to the system under test.

d) Freeze/spray, upon completion of humidity freeze cycling: the chamber will be brought to 25 °C and maintained at this temperature for 24 h. At this point, the drive train and control box shall be sprayed with water from all sides. Water jets shall consist of a low-pressure steady stream of 15,5 l/min (± 5 %) from a 6,3 mm nozzle diameter for a minimum of 3 min. The nozzle shall be placed 2,5 m to 3 m from the tracker drive train and enclosure surfaces. For large areas, duration of the spray shall be a minimum of 1 min per square m of surface.

After spray is completed, the chamber shall be closed and the temperature reduced to –15 °C. The chamber shall be maintained at –15 °C for 24 h and then shut off.

Between each consecutive section of environmental testing, the chamber shall be opened and a visual inspection shall be completed. Fluid leaks, corrosion, and other external wear, which are not failures but may be of future concern, shall be documented with photographs.

After the final water-spray freeze test, the drive train shall be cycled through one final continuous duty cycle. Each axis of rotation shall be loaded to the maximum specified payload (i.e., weight of structural framing combined with modules, or mirrors, but no external loading such as wind). This movement shall be done using all components and the controller that was subjected to environmental testing per 8.5. The maximum specified payload can be applied as a separate torque to each axis of rotation through any suitable method. It is not intended that an actual payload structure be attached to the drive train under test unless this is the most economical means to test the drive train under load. For example, a lever arm could be attached to the elevation axis and weights applied per manufacturer’s recommendations. The energy used and the time to complete the final duty cycle shall be recorded. A final external visual inspection shall be completed. Photographs shall be used to document fluid leaks, corrosion, wear, or other abnormalities. After completion of the external visual inspection, the drive train and control box shall be disassembled and the same inspection/documentation process shall be repeated for the internal components.

8.5.3 Requirements

To pass the accelerated environmental testing, all the following shall be true:

a) The drive train shall be able to complete the continuous duty cycles prescribed in the procedure (with the exception of allowed stoppages as described in the procedure).

b) The drive train shall be able to complete the final duty cycle after the final water-spray freeze test and before disassembly. The energy use and time required to complete the cycle shall be within 20 % of the measurements taken prior to environmental cycling.

c) Water ingress shall not:
   - Be sufficient to interfere with correct operation of the equipment or impair safety.
   - Reach live parts or windings not designed to operate when wet.

d) No major cracks shall be found on any housing or any component of the drive train per the following list (all other cracks shall be documented, but do not constitute a failure):
   - A crack that allows lubrication or drive train fluid to drain from the system; this does include a slow leak.
   - Cracks that impair sound structural functioning or present potential harm to persons working around the tracker.
   - Cracks that impact sound electrical functioning of the tracker.

e) Wiring shall not show abrasions or fraying that expose the conductor material. Twisting shall not result in a bend radius less than 12 times the diameter of the individually shielded/insulated conductor or less than seven times the overall diameter of a multiconductor packaged cable.

f) No faulty or loose terminals shall be found.

g) No loose screws, bolts, nuts, or grommets, which present a safety hazard. All loose screws, bolts, nuts, or grommets shall be documented in the test report.

h) Validation of specified operational temperatures (8.2.8) shall be successful.

8.6 Accelerated mechanical cycling

8.6.1 Purpose

The overall objective of this testing is to attempt to induce failures or infant mortality associated with design that may occur as a result of accelerated cycling of the drive system, control system, and associated wiring. Because the following tests depend on the interaction between the drive system and the control system, design iterations that alter any of the above components would require retest to be in compliance with this standard.

8.6.2 Procedure

The tracker shall be installed according to 7.4.2.1. The test setup shall include standard wiring for drive train control and a mock-up of payload wiring that will typically cross through or around the drive train. Once the drive train and controls have been installed, photos shall be taken and a visual inspection shall be completed.

A cycle of drive train operation shall consist of both axes being driven from one limit extreme to the other and back again. The manufacturer shall provide a means to command the controller to simultaneously cycle both axes in a continuous loop. Motion for this continuous loop shall accelerate typical on-sun movements while still holding start/stop or continuous movement patterns normally employed by the given tracker on a day that has 12 h between sunrise and sunset. Figure 12 portrays a sun-tracking profile where t_{step} is the normal discrete movement to follow the sun and t_{pause} is the pause associated with the sun moving within the acceptable pointing error of the tracker. t_{wait} is the long pause before or after returning the tracker to the beginning of the day position and t_{drive} is the time associated with moving the tracker to the beginning of the day position. For the purposes of mechanical cycling, it is important that the accelerated cycle mimic the normal wear mechanisms associated with the typical use cycle. For this reason, the accelerated cycle shall have the same number of start/stop instances as tracking on a day with 12 h of sunshine. The manufacturer shall calculate the average number of start/stop events per day for each axis, assuming the sun moves 180° in azimuth and ± 50° in elevation on the typical day. The accelerated cycle for the drive train shall have the same number of start/stop events for each axis as calculated for the typical day. For an azimuth axis, it is expected that start/stops will be progressively moving the tracker toward the western limit, whereas for an elevation axis, half the events should be moving the tracker up and the other half moving it down.

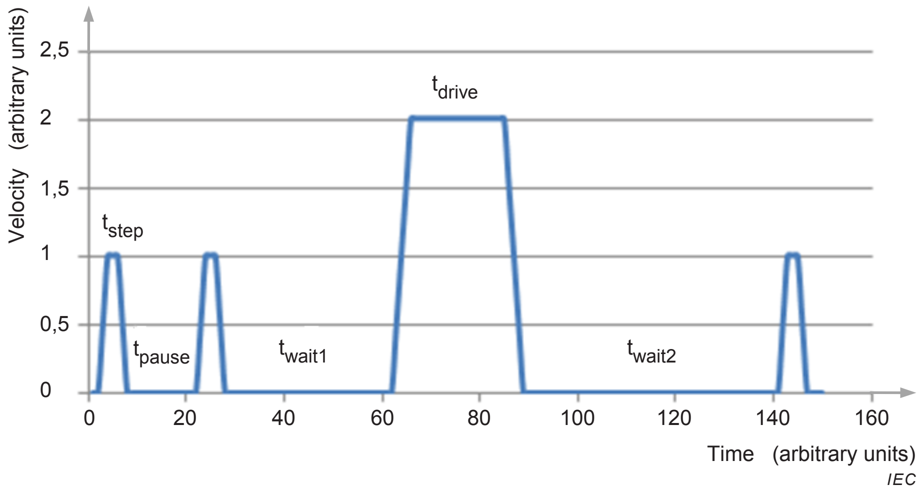


Figure 12 – Representation of a tracker's discrete-movement profile

To meet the above requirements in a shortened time period, the accelerated cycle might look like Figure 13, where all pause times have been significantly reduced and the step times and velocities have been increased. However, Figure 13 only serves as an example, while actual accelerated cycles will depend on the tracker's typical operational profile.

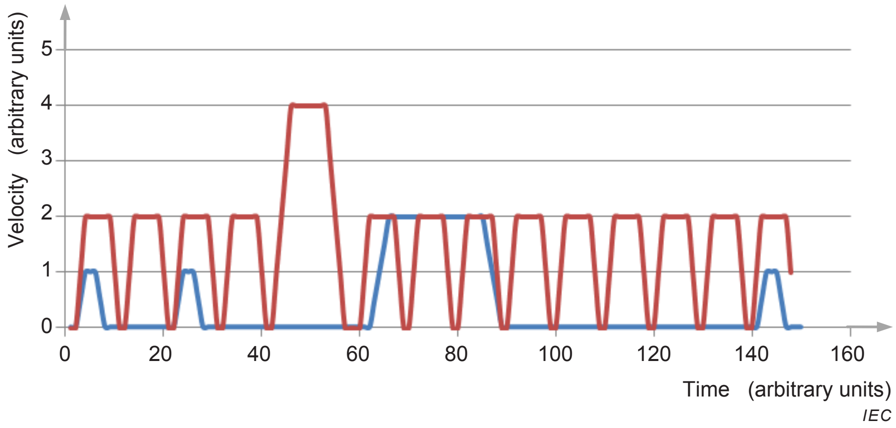


Figure 13 – Representation of an accelerated discrete-movement profile for testing

An alternate option to looping through a "typical drive-train cycle" is to accelerate the controller clock so that actual sun-tracking movements are completed as they would be throughout an astronomical year, but at the accelerated pace (this option is only viable for a controller that is driven by astronomical calculations). Timed breaks can be inserted between cycles to maintain the temperature of drive train components.

Because accelerated cycling can place abnormal heating loads onto the actuator system, motors, pumps, and power supplies, it is also permissible to employ external cooling to motors, pumps, or other drive components. If external cooling is employed, in no case shall it be used to achieve temperatures below ambient or below the normal expected operating temperature. Normal expected operating temperature can be determined by measuring the rise above ambient temperature of relevant drive train components on a clear, sunny day when the DNI is above 850 W/m^2.

The system shall complete 3 650 cycles (10 years times 365 days per year). Although there is no limit to cycle time, this test can be lengthy if not minimized. As an example, a cycle time of 24 min and no down-time equates to a total test time of 2 months.

Electro-mechanical system components may not all be designed to function for 10 years without basic preventative maintenance (PM) such as lubrication, oil change, or corrective maintenance (CM) to repair or replace components that may wear out or fail. During the course of this test, the system shall be stopped to perform PM and CM that is determined by the manufacturer and communicated to the test lab prior to the start of mechanical cycling. If any component fails prior to the time in the CM plan, then this is considered failure to pass the test. The manufacturer may also plan and communicate test interruption for other reasons. For example, it may be beneficial to run the 3 650 accelerated cycles at night so that the tracker can be allowed to track the sun during the day. The predetermined PM, CM, and interruption plan shall be recorded as part of the test report. The test report shall document the time required for each planned PM stoppage and the time required for each CM stoppage along with a list of all components repaired or replaced. The report shall also document the tracker system availability. For the purpose of this test, the availability shall be defined as the total hours of the test period minus the result of combined down time for PM and CM divided by the total hours of the testing period. The total hours of the test period shall not include the predetermined interruptions for daytime tracking or other reasons not associated with accelerated cycling. The manufacturer shall provide a technical team for the needed preventative and corrective maintenance. The test clock shall stop at the intervals planned for PM and CM and resume when the technical team is on site to begin the scheduled services. This is to avoid undue penalty for scheduled maintenance that might fall on a weekend or for long travel times associated with getting to the test lab. Video, event recorders, or other suitable instrumentation and methods shall be used to track operational time and down time.

8.6.3 Requirements

a) Recording devices shall provide verification that 3 650 cycles were completed without failure.

b) Water ingress shall not:
  - Be sufficient to interfere with correct operation of the equipment or impair safety.
  - Reach live parts or windings not designed to operate when wet.

c) No major cracks shall be found per the following list (all other cracks shall be documented but do not constitute a failure):
  - A crack that allows lubrication or drive train fluid to drain from the system; this does include a slow leak.
  - Cracks that impair sound structural functioning or present potential harm to persons working around the tracker.
  - Cracks that impact sound electrical functioning of the tracker.

d) Wiring shall not show abrasions or fraying that expose the conductor material. Twisting shall not result in a bend radius less than 12 times the diameter of the individually shielded/insulated conductor or less than seven times the overall diameter of a multiconductor packaged cable.

e) No faulty or loose terminals shall be found.

f) No loose screws, bolts, nuts, or grommets, which present a safety hazard. All loose screws, bolts, nuts, or grommets shall be document in the test report.

g) The tracking accuracy test shall be completed according to 7.4 both before and after mechanical cycling. Tracking accuracy testing after mechanical cycling can be limited to just the array maximum deflection point and the low wind condition. 95th percentile accuracy before and after mechanical cycling shall be within 20 % in order to pass.

h) No component shall be replaced other than those communicated in the CM plan. If a component specified in the CM plan fails prior to the specified replacement time, then this constitutes a failure.

9 Design qualification testing specific to tracker electronic equipment

9.1 General purpose

Electronic equipment can have separate failure mechanisms from that of the mechanical equipment associated with trackers. For this reason, it is not meaningful or cost effective to test all the equipment using one common set of tests. The following tests are specifically designed to uncover early failures associated with the tracker's electronic components system (ECS). The ECS consists of control electronics, power supplies, sensors, encoders, and enclosures, but does not include drive components such as motors, pistons, valves, pumps, or equipment that is generally under a mechanical classification. Because different tracker mechanical designs can employ a common control system, it is expected that a tracker ECS only needs to be tested once per Clause 9. Although testing to Clause 9 certifies the ECS for tracking use, a given tracker design only passes the entire design qualification standard when it is coupled with an ECS for the testing of Clauses 7 and 8. The combined components of the ECS provide the ability to control the tracker system, and therefore, the functionality of the ECS system shall be tested as a whole.

9.2 Sequential testing for electronic components

9.2.1 General

Three samples of the given component shall be subjected to the test sequence given in Figure 14. The description of each test follows.

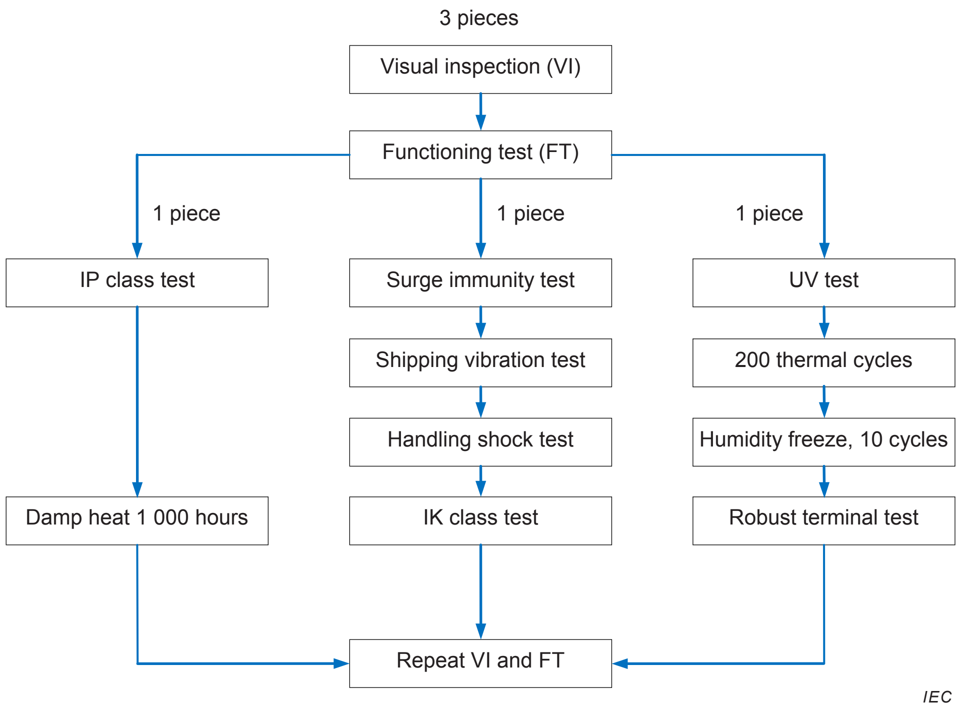


Figure 14 – Test sequence for electronic components

9.2.2 Visual inspection of electronic components

9.2.2.1 Purpose

The purpose of this test is to detect any visual defects pertaining to tracker electronic components. Visual inspection is performed before and after the sequential testing and serves to catch and document a wide range of unknown problems that could arise due to the performed tests. Unless specified in the requirements, visual defects do not constitute failures.

9.2.2.2 Procedure

Carefully inspect each electronic component for the following conditions. Document all defects found in written and photographic form. Circuit boards shall be inspected under 40X magnification.

- Broken, cracked, bent, or misaligned parts.
- Corrosion on electrical connectors, interconnections, or bus bars.
- Solder joint cracks, dendrites, printed circuit-board delamination.
- Visual corrosion of enclosure surfaces.
- Cracked, frayed, or otherwise damaged wire or cable.
- Loose or faulty terminals, exposed energized electrical parts.
- Any other conditions that might affect functioning, performance, or safety.

Make notes of any visual conditions that worsen or change over the course of testing.

9.2.2.3 Requirements

To pass both the initial and final visual inspection, there shall be none of the following:

- Defects that present a safety issue.
- Defects that inhibit normal functionality.

- Solder joint cracks/or component disconnection.
- Printed circuit-board delamination.
- Cracked circuit-board components.

9.2.3 Functioning test

9.2.3.1 Purpose

The purpose of the functioning test is to confirm that the ECS performs as designed, primarily meaning the ability to control the tracker structure. The test is performed both before and after the sequential testing and serves as the primary pass/fail criterion.

9.2.3.2 Procedure

The ECS system shall either be installed outdoors on the tracker per 7.4.2.1 or installed in a test-bench-type setup.

If installed outdoors, the following shall be completed to verify functionality:

a) 4 h of on-sun tracking with clear-sky conditions. Drive train pointing-repeatability testing per 8.4.2 can be used in lieu of on-sun tracking if the controller does not use a solar irradiance feedback sensor.

b) Verify the ability to move each relevant axis in each rotational direction.

c) If included, verify that stow can be triggered and achieved.

d) Verify that, when triggered, all included switches for stopping motion (e.g., limit switches, manual switches, stop switches, hard limit switches) result in powered motion coming to a halt. The said switches shall be mechanically triggered, but this can be done by any means that the test lab finds appropriate.

e) If manual controls apply, verify that all manual functions operate as intended.

f) Perform a 50° (or full range of motion, whatever is smaller) sweep in each relevant axis in each rotational direction while measuring energy usage (total energy of both the actuator and controller) with an energy transducer with an accuracy of 1 % or better. The energy used to complete this sweep shall be within 15 % from the initial to the final functional test.

Although on-sun testing is considered the most robust functional test for the ECS, a test-bench setup can provide benefits in terms of cost and availability. The following shall be completed to verify functionality on a test bench:

g) The ECS shall be connected to an actuation system that is appropriate to its design (e.g., hydraulic pump/valve/piston, DC motors, AC motors). Encoders, feedback sensors, limit switches, and all other ECS components shall be tied into the actuation system. The manufacturer shall be allowed to provide loading for the actuation system if this is necessary for the controller to function as designed.

h) Verify the ability of the control system to move each actuator in all relevant directions.

i) Verify the ability of the controller to move each actuator to a predetermined location. If the controller uses feedback from a sun-position sensor, then a moveable light source of at least 100 W/m^2 and a collimation angle of 1° or smaller shall be incorporated into the testing. The light source and the feedback sensor shall be aligned. With an alignment achieved, confirm that the control system stabilizes and all actuation halts. Perturb the light source by 1° in one angle of rotation. Confirm that the actuation system responds and again aligns with the light source. Repeat the process for all rotational directions and again for a 5° perturbation.

j) If included, trigger stow and verify that actuators move to the correct locations.

k) Verify that, when triggered, all included switches for stopping motion (e.g., limit switches, manual switches, stop switches, hard limit switches) result in actuator motion coming to a halt. The said switches shall be mechanically triggered, but this can be done by any means that the test lab finds appropriate.

l) If manual controls apply, verify that all manual functions operate the actuators as intended.

m) Measure current and voltage at the following locations:
   - power input to the controller;
   - output power from the controller to relays, valves, sensors, or to actuation;
   - primary power feed to the actuation system.

9.2.3.3 Requirements

a) All listed verifications in the procedure section shall be achieved.

b) If outdoor testing is completed, typical tracking accuracy at the minimum deflection point and low wind condition shall be within 20 % for before and after functional testing (see Clause 7). Because feedback and other sensors may need to be removed from the tracker for ECS testing, realignment of said sensors with pointing-error measurements is expected.

c) If outdoor testing is completed and drive train pointing is used in lieu of tracking accuracy, pointing repeatability shall be within 10 % for before and after functional testing.

d) All current and voltage measurements shall be within normal ranges as specified by the manufacturer before the onset of the test. Maximum current and voltage measurements from initial and final functional testing shall be within 15 %, assuming the ECS is installed with similar actuation equipment for both initial and final testing.

9.2.4 Protection against dust, water, and foreign bodies (IP code)

9.2.4.1 Purpose

The degree of protection (IP code) defines the extent to which an enclosure provides protection against access to dangerous parts, the penetration of solid foreign bodies, and/or the entry of water dust, as proved by standard testing methods.

9.2.4.2 Requirements

All ECS enclosures at minimum shall meet IP54. The tests are conducted in conformance with IEC 60529. If an enclosure being used for the ECS has already been certified with at least an IP54 rating, then this test does not need to be repeated.

9.2.5 Protection against mechanical impacts (IK code)

9.2.5.1 Purpose

The degree of protection (IK code) defines the extent to which an enclosure provides protection against mechanical impact.

9.2.5.2 Requirements

The tests are conducted in conformance with IEC 62262 using the pendulum hammer described in IEC 60068-2-75 (test Eha). The equipment is preconditioned for 1 h at –10 °C in a chamber; the test is performed within 1 min of its removal in normal laboratory atmospheric conditions. The methods of this test are described in Annex D of IEC 62262:2002. The equipment is set up according to preparation method 1.

The required IK class for all ECS enclosures is IK05.

The enclosure shall show no cracks or distortions that could be detrimental to its operation. If an enclosure being used for the ECS has already been certified with an IK05 rating, then this test does not need to be repeated for that enclosure.

9.2.6 Robustness of terminals test

9.2.6.1 Purpose

The purpose of this test is to determine that the terminals and the attachment of the terminals to the component withstand such stresses as are likely to be applied during normal assembly and handling operations.

9.2.6.2 Types of terminals

Three types of component terminals are considered:

- Type A: wire or flying lead;
- Type B: tags, threaded studs, screws, etc.;
- Type C: connector.

9.2.6.3 Procedure

9.2.6.3.1 General

Preconditioning: 1 h at standard atmospheric conditions for measurement and test.

9.2.6.3.2 Type A terminals

Tensile test: as described in IEC 60068-2-21, test Ua, with the following provisions:

- All terminals shall be tested.
- Tensile force shall never exceed the component weight.

Bending test: as described in IEC 60068-2-21, test Ub, with the following provisions:

- All terminals shall be tested.
- Perform 10 cycles (one cycle is one bend in each opposite direction).

9.2.6.3.3 Type B terminals

Tensile and bending tests:

a) For components with exposed terminals, each terminal shall be tested as for type A terminals.
b) If the terminals are enclosed in a protective box, the following procedure shall be applied.

A cable of the size and type recommended by the component manufacturer, cut to a suitable length, shall be connected to the terminals inside the box using the manufacturer’s recommended procedures. The cable shall be taken through the hole of the cable gland, taking care to use any cable clamp arrangement provided. The lid of the box shall be securely replaced. The component shall then be tested as for type A terminals.

Torque test: as described in IEC 60068-2-21, test Ud, with the following provisions:

- All terminals shall be tested.
- Severity 1.

The nuts or screws shall be capable of being loosened afterward, unless they are specifically designed for permanent attachment.

9.2.6.3.4 Type C terminals

A cable of the size and type recommended by the component manufacturer, cut to a suitable length, shall be connected to the output end of the connector, and the tests for type A terminals shall be carried out.

9.2.6.4 Requirements

The ECS shall pass visual inspection and functional testing and there shall be no evidence of mechanical damage.

9.2.7 Surge immunity test

9.2.7.1 Purpose

The purpose of the power surge test is to test the ability of electronic equipment associated with the tracker (control electronics, power supplies, sensors, encoders etc.) to handle over voltages associated with lightning, switching, or other short voltage transients.

9.2.7.2 Procedure

All electronics, controllers, and power supplies that are part of the tracker system shall be subject to IEC 61000-4-5 (Testing and measurement techniques, Surge immunity test). The tracker electronic equipment shall be considered class 3 (electrical environment where cables are run in parallel), unless it can be documented that a lower/less stringent classification is appropriate for the device under test.

9.2.7.3 Requirements

Electronic equipment subjected to IEC 61000-4-5 shall not pass if IEC 61000-4-5:2005, Clause 9d is true (loss of function or degradation that is not recoverable). The final visual inspection and functional testing requirements shall be met.

9.2.8 Shipping vibration test

9.2.8.1 Purpose

The purpose of this test is to identify mechanical weak points and/or to ascertain any deterioration of the specified parameters. According to IEC 60068-2-6, it shall be conducted on structural elements or devices that are exposed to harmonic vibrations during shipment, such as occur on ships, aircraft, and land vehicles.

9.2.8.2 Degree of stringency

Frequency range:	10 Hz to 11,8 Hz; 11,9 Hz to 150 Hz
Constant amplitude:	3,5 mm
Constant acceleration:	2 g
Cycling:	1 octave/min
Duration on each axis:	2 h
Total test duration:	6 h

9.2.8.3 Procedure

See IEC 60068-2-6. The specimens are not energized during the test but may be packaged. as designed for shipping.

9.2.8.4 Requirements

The final visual inspection and functional testing requirements shall be met.

9.2.9 Shock test

9.2.9.1 Purpose

In conjunction with the previous test, the purpose of this test is to discover mechanical weak points and/or to determine whether the specified parameters are maintained or deteriorate. The tests are conducted in conformance with IEC 60068-2-27.

9.2.9.2 Degree of stringency

Amplitude of acceleration:	15 g
Type of shock:	half-sine
Duration of shock:	11 ms
Sequence of shocks:	1 s
Number of shocks:	18 (6 × 3)

9.2.9.3 Procedure

See IEC 60068-2-27. The specimens are neither packaged nor energized during the test.

9.2.9.4 Requirements

The final visual inspection and functional testing requirements shall be met.

9.2.10 UV test

9.2.10.1 Purpose

The purpose of this test is to determine the ability of the component to withstand exposure to ultraviolet (UV) radiation. This test only applies to polymeric/electric/electronic components that are not protected by enclosures.

9.2.10.2 Apparatus

The apparatus consists of the items listed below:

a) A temperature-controlled test chamber or other arrangement with a window or fixtures for a UV light source and the component under test. The chamber shall be capable of maintaining the component temperature at (60 ± 5) °C and a dry condition.

b) A UV light source capable of producing UV radiation with an irradiance uniformity of ±15 % over the test plane of the component and capable of providing the necessary total irradiance in the different spectral regions per the procedure. The test report shall indicate which UV light source is used.

c) Means for measuring and recording the surface temperature of the component to an accuracy of ±2 °C.

d) A calibrated radiometer capable of measuring the UV irradiance at the test plane of the component(s).

9.2.10.3 Procedure

a) Use the calibrated radiometer to measure the irradiance at the proposed component test plane and ensure that, at wavelengths between 280 nm and 400 nm, the test spectral irradiance is never more than five times the corresponding standard spectral irradiance specified in the standard AM 1.5 solar irradiance distribution given by Table 1 of IEC 60904-3:2008, that there is no appreciable irradiance at wavelengths below 280 nm, and that it has a uniformity of ±15 % over the test plane.

b) Mount the component in the test plane at the location selected in a) with the most critical side (e.g., the side with the most wire or cable penetrations) normal to the UV irradiance beam. If the component is normally installed in an orientation to shield a particular side from incident sunlight, then the component may be installed in this orientation in the chamber.

c) While maintaining the component temperature within the prescribed range, subject the component to a minimum irradiance of 15 kWh/m^2 in the wavelength range between 280 nm and 400 nm with 3 % to 10 % of the total energy within the wavelength band between 280 nm and 320 nm.
d) Reorient the component so that the backside is normal to the UV irradiance beam.
e) Repeat step c) for 10 % of the time at the irradiation levels that were performed on the front side.

9.2.10.4 Requirements

The final visual inspection and functional testing requirements shall be met.

9.2.11 Thermal cycling test

9.2.11.1 Purpose

The purpose of this test is to determine the ability of the component to withstand thermal mismatch, fatigue, and other stresses caused by repeated changes of temperature.

9.2.11.2 Procedure

The electronic component shall be subjected to 200 thermal cycles per Figure 15, where the maximum temperature is 85 °C and the minimum temperature is –40 °C.

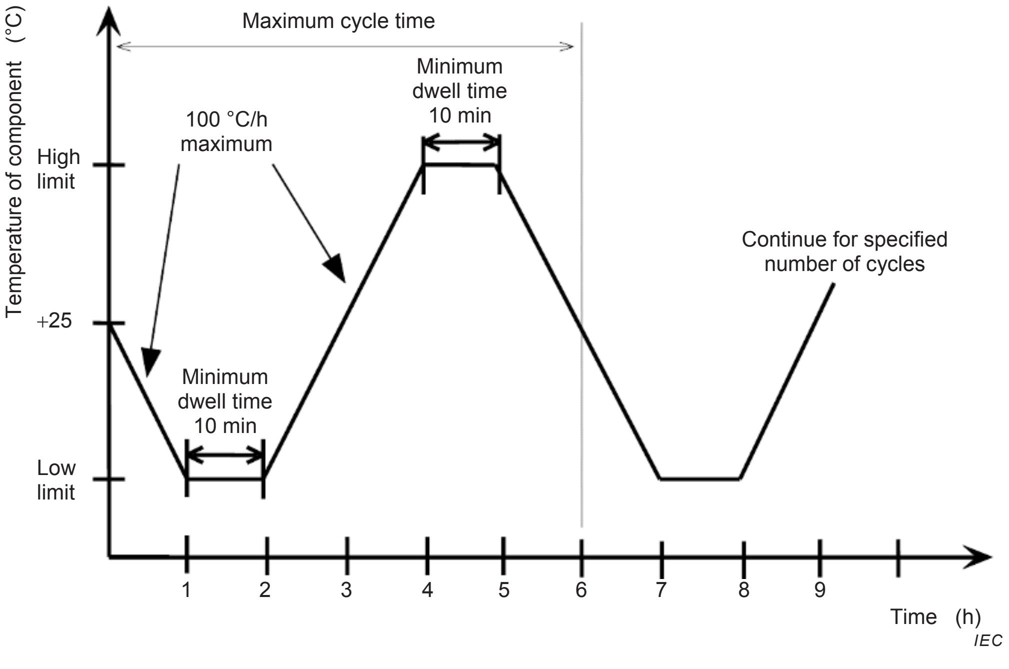


Figure 15 – Electronic component thermal cycling test

a) Install the component at room temperature in the chamber. If the component enclosure is a poor electrical conductor, then mount the component on a metal frame.
b) Attach a temperature sensor (accuracy of ± 2 °C) to the the surface of the component. Connect the continuity instrumentation across the component terminals. Connect the insulation monitor between one terminal and the frame supporting structure.
c) Close the chamber, with the air around the component(s) circulating at a velocity of not less than 2 m/s, and subject the component to cycling according to the profile in Figure 15.

d) Throughout the test, record the component temperature and monitor the component(s) to detect an open circuit or ground faults that may occur during the exposure.

9.2.11.3 Requirements

The final visual inspection and functional testing requirements shall be met. There shall be no intermittent open circuits or ground faults detected during the test.

9.2.12 Humidity-freeze test

9.2.12.1 Purpose

The purpose of this test is to determine the ability of the component to withstand the effects of high temperature and humidity followed by a cold temperature. This is not a thermal shock test.

9.2.12.2 Procedure

The component will be subjected to 10 humidity-freeze cycles per Figure 16 with a maximum temperature of 85 °C and a minimum temperature of –40 °C.

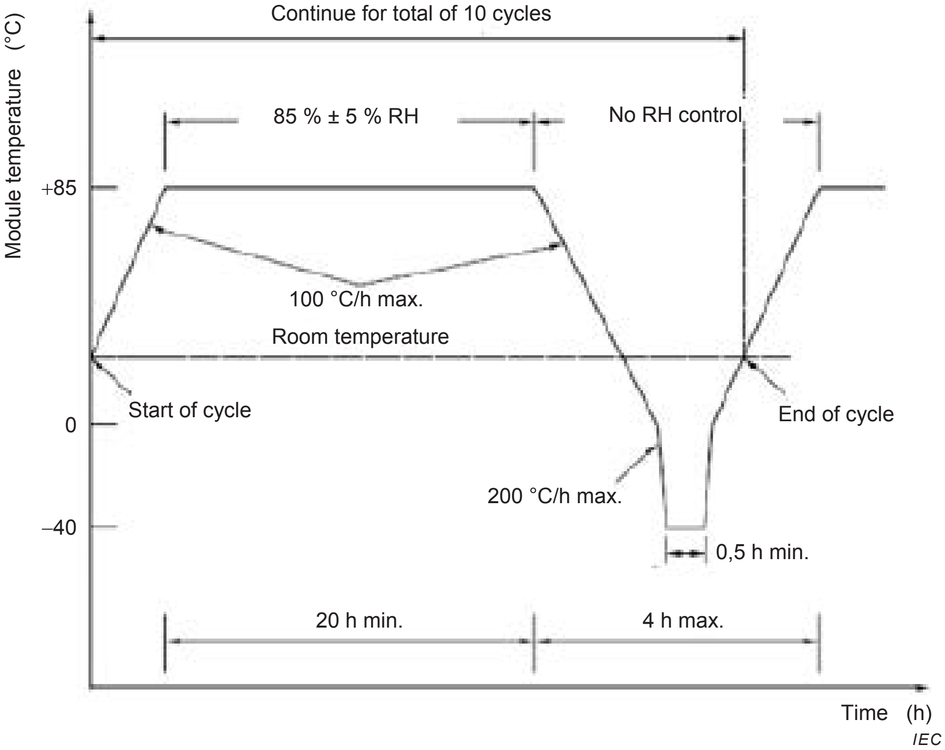


Figure 16 – Electronic component humidity-freeze test

a) Install the component at room temperature in the chamber at an angle of not less than 5° to the horizontal. If the component enclosure is a poor electrical conductor, then mount the component on a metal frame.

b) Attach a temperature sensor (accuracy of ± 2 °C) to the the surface of the component. Connect the continuity instrumentation across the component terminals. Connect the insulation monitor between one terminal and the frame supporting structure.

c) Close the chamber and subject the component to cycling according to the profile in Figure 16. Maximum and minimum temperatures shall be maintained within ± 5 °C and relative humidity within ± 5 %.

d) Throughout the test, record the component temperature and monitor the component(s) to detect any open circuits or ground faults that may occur during the exposure.

9.2.12.3 Requirements

The final visual inspection and functional testing requirements shall be met. There shall be no intermittent open circuits or ground faults detected during the test.

9.2.13 Damp heat

9.2.13.1 Purpose

The purpose of this test is to determine the ability of the components to withstand the effects of long-term penetration of humidity.

9.2.13.2 Procedure

The component will be subjected to 1 000 h of (85 ± 5) % relative humidity at a temperature of (85 ± 5) °C. Install the component at room temperature in the chamber at an angle of not less than 5° to the horizontal.

9.2.13.3 Requirements

The final visual inspection and functional testing requirements shall be met.

10 Additional optional accuracy calculations

10.1 Typical tracking accuracy range

If it is desired to further simplify the table of eight accuracy values in the “Accuracy Calculations” presented in 7.4.6, then the following process may be followed:

“Tracker accuracy (typical best)” is the result from the low wind, typical accuracy, and array min deflect point. For example, from the data in Table 2, this would be reported as 0,4°. This is one way of providing a quick value for a “typical good conditions with minimal deflection” error.

“Tracker accuracy (typical worst)” is the result from the high wind, 95th percentile accuracy, and array max deflect point. For example, in Table 2, this would be reported as 1,4°. This is one way of providing a single number as a roughly “worst case error” for design guidance, although it will not be an absolute worst possible case (this is intentional, to avoid the influence of one or two rare outlier data points).

These two values can be combined into a simplified metric for the accuracy range, “typical tracking accuracy: best-worst.” For example, from the data set used to generate Table 2, the accuracy would be reported as “typical tracking accuracy range: 0,4° to 1,4°.”

10.2 Tracking error histogram

In addition to the above, pointing error can optionally also be graphed as a histogram, showing the frequency of different error magnitudes for the entire test period as shown in Figure 17 below.

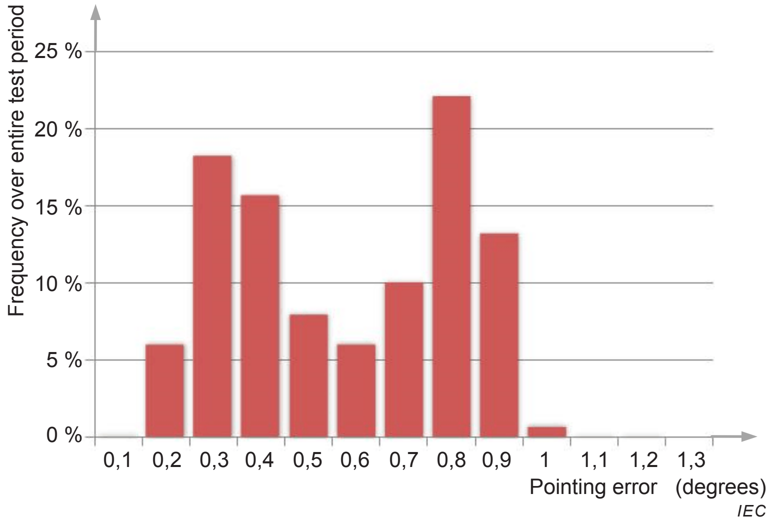


Figure 17 – Pointing-error frequency distribution for the entire test period

10.3 Percent of available irradiance as a function of pointing error

Pointing error data can be combined with DNI data to generate a graph that weights measured pointing error based on the DNI that was present.

Sort the collected pointing error data by ascending tracking error.

For each pointing error, calculate the integral (or cumulative sum) of the DNI values at or below that error, and graph the results as shown in Figure 18.

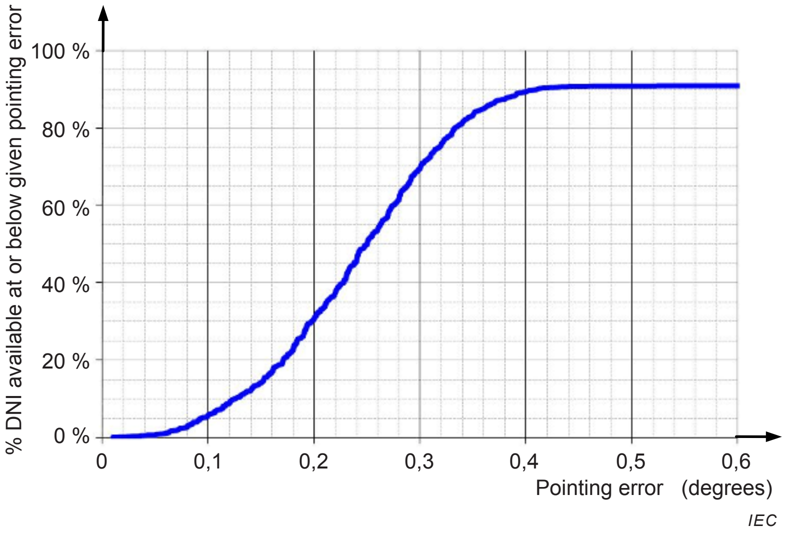


Figure 18 – Available irradiance as a function of pointing error

If desired, divide the initial data into bins by any parameter of interest (e.g., wind speed), and perform the above process on each bin separately. An example is shown in Figure 19.

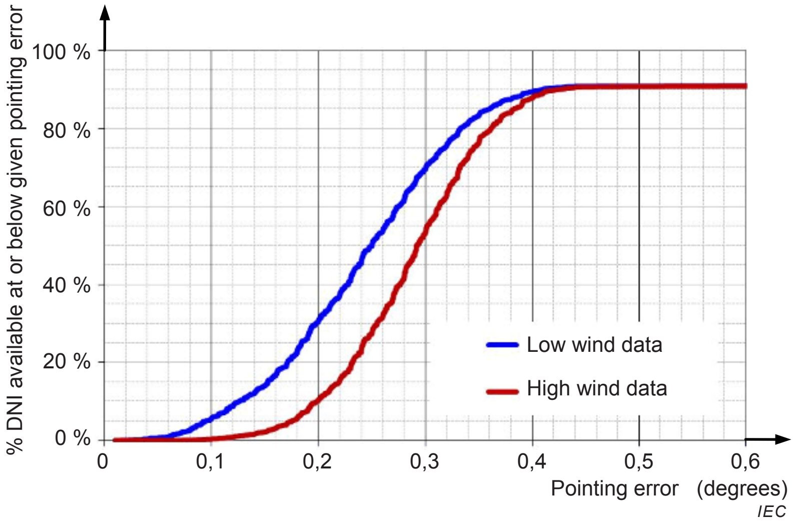


Figure 19 – Available irradiance as a function of pointing error with binning by wind speed

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