Solar Power and Chemical Energy Systems
IEA Technology Collaboration Programme

SolarPACES Guideline for Heliostat Performance Testing

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Edited by Marc Röger

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Further information on the IEA-SolarPACES Program can be obtained from the Secretary, from the Operating Agents or from the SolarPACES web site on the Internet https://www.SolarPACES.org.

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Contents

Foreword

SolarPACES is an international cooperative network bringing together teams of national experts from around the world to focus on the development and marketing of concentrating solar power systems (also known as solar thermal power systems). It is one of a number of collaborative programs, called Implementing Agreements, managed under the umbrella of the International Energy Agency to help find solutions to worldwide energy problems. Within SolarPACES several international Task-activities coordinate the work.

The objectives of Task III “Solar Technology and Advanced Applications” deal with the advancement of technical and economic viability of emerging solar thermal technologies and their validation with suitable tools by proper theoretical analyses and simulation codes as well as by experiments in special arrangements and adapted facilities. For this purpose, procedures and techniques are defined for the design, evaluation and use of the components and subsystems to optimize concentration, reception, transfer, storage and application of solar thermal energy. In essence, the goals are to investigate innovative multi-discipline advances needed for the further development of concentrating solar thermal systems. This also concerns, among others, process heat applications, the utilization of solar concentration for the development of improved materials, and the introduction of hybrid solar/fossil power plant concepts.

A group of R&D and industry experts in the field of heliostats and concentrator measurement techniques has been working together as members of Task III to create this heliostat guideline. The guideline for heliostat performance testing contains an internationally reviewed, concisely defined parameter list to describe heliostats and their performance. Measurement techniques or other techniques to derive the parameters are suggested. The content of this document shall be the basis for international standards (e.g. IEC) and should be used by national organizations like DKE, AENOR, ASME, ASTM and international organizations for this purpose.

Funding from several national agencies to develop the measurement techniques is gratefully acknowledged. The developed measurement techniques form the basis for this guideline. We especially acknowledge the European Union for the funding of the SFERA-II and SFERA-III projects (grant 312643 and 823802) and the Federal Republic of Germany for the Saphir and Heliodor projects (grant 16UM0068 and 0324310) which allowed the redaction, international discussion and update of this document.

1. Scope and Objective of Guideline

This guideline focuses on Concentrating Solar Technologies (CST). Power tower or central receiver systems use 2-axis tracking mirrors, so called heliostats, which reflect and focus the sunlight onto a receiver on top of a tower during the day for heat, electricity or fuel production. The document's content is fed into the IEC 62862-4-3 Part 4-3: Heliostat requirements and testing started in 2023.

The "**Heliostat Performance Testing**" guideline is directed to heliostats of CST central receiver systems. It focuses on the definition of parameters and performance testing of single heliostats during a limited time period. Measurement techniques or other techniques to derive the heliostat parameters are suggested. Durability issues are treated in this guideline only in the sense that the heliostat performance can be tested from time to time. Accelerated ageing and durability tests are not in the scope of this guideline. Although performance testing of a whole heliostat field (consisting of several heliostats with blocking/shading effects, aimpoints issues, etc.) will be based on the "Heliostat Performance Testing" guideline, the aspects of interaction of the heliostats in a solar field will be treated in a separate guideline called "Heliostat Field Performance Acceptance Test Guideline".

The objective of this guideline is to serve as a commonly agreed protocol between R&D centers and industry in the field of heliostat performance testing. It is ready to be included in international standards (e.g. IEC) and should be used by national organizations like DKE, AENOR, ASME, ASTM and international organizations for this purpose. The application of this guideline will result in homogenized content of heliostat test certificates which are issued by the different qualification centers. Consequently, bankability of new heliostats should be facilitated. The objective of performance testing of different heliostats according to protocols is to assess heliostat performance on an objective, scientific, but practical level.

2. Normative References

The following referenced documents may be relevant for the application of this guideline. The references are undated; the latest edition of the referenced document (including any amendments) applies. Definitions in these referenced documents are valid, as long as they are not defined differently in this document.

- IEC TS 62862-1-1:2018: Part 1-1: Terminology
- IEC 62862-1-x Part 1-x: Mirrors for CSP plants
- IEC TS 62862-3-5: Part 3-5: Laboratory reflectance measurement of concentrating solar thermal reflectors
- IEC TS 62862-3-6: Part 3-6: Accelerated aging tests of silvered-glass reflectors for concentrating solar technologies
- IEC 62862-4-1: Part 4-1: General requirements for the design of solar tower plants
- IEC 62862-4-2: Part 4-2: Heliostat field control system
- ISO 9806:2013 Solar energy - Solar thermal collectors - Test methods (Hailstone Test)
- AENOR UNE 206016: Reflector Panels for Concentrating Solar Technologies
- SolarPACES Reflectance Guideline: Parameters and method to evaluate the solar reflectance properties of reflector materials for concentrating solar power technology. (Available online: http://www.solarpaces.org/).
- SolarPACES Guideline: Guideline for accelerated aging for silvered-glass mirrors and silvered-polymer films (preparation in task III group)
- SolarPACES Guideline: Guideline for accelerated sand erosion testing of reflectors for concentrating solar power technology (preparation in task III group)
- SolarPACES Guideline: Guideline for measurement and assessment of mirror shape for concentrating solar collectors (preparation in task III group)
- SolarPACES Guideline: Best practices for Heliostat Field Performance Testing (launched in task III group)
- SolarPACES Guideline: Recommendations for reflectance measurements on soiled solar mirrors (draft version 2022)

3. Symbols and General Definitions

Figure 1 visualizes the most important coordinate systems in this document.

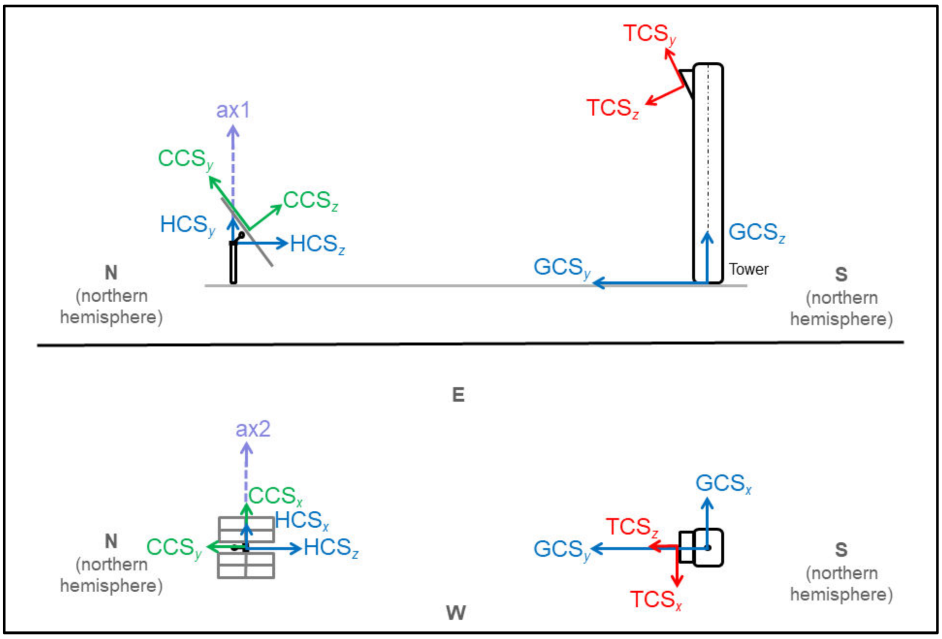

Figure 1: Sketch of relevant coordinate systems.

Global Coordinate System (GCS). (x_{GCS}, y_{GCS}, z_{GCS}). Right-handed coordinate system describing positions of tower, receiver and heliostats, with *x* being oriented east, *y* north and *z* vertical up for the northern hemisphere, and *x* being oriented west, *y* south and *z* vertical up. The origin has to be defined. Usually the origin is on the north-south symmetry plane of the solar field at tower ground level, either in the aperture plane of the receiver or in the case of a cylindrical receiver in its central axis at ground level.

Heliostat Coordinate System (HCS). (x_{HCS}, y_{HCS}, z_{HCS}). Right-handed local cartesian coordinate system defined for each heliostat which does not move with the concentrator movement, with *z* being the vector pointing south for the northern hemisphere (*z* pointing north for the southern hemisphere) or, alternatively, pointing to the tower (must be defined!), and *y* being the vertical axis. The origin could be the intersection of the two tracking axes.

Concentrator Coordinate System (CCS). (x_{CCS}, y_{CCS}, z_{CCS}). Right-handed local cartesian coordinate system on the concentrator which moves with concentrator elevation and azimuth with *z* being the concentrator surface normal pointing away from the mirror surface and *y* being the vertical axis projected into the concentrator plane (for elevations in the range between 0 and <90°). The origin has to be defined. It should be on the concentrator central axis so that the lowest *z* value of the reflective surface is close to zero and the rest of the z values are positive. For other concentrator shapes (e.g. rotation symmetric) differing systems, e.g. polar coordinates, using the index CCS can be used.

Heliostat Axis System (AS). (*ax1*, *ax2*). Coordinate system on the heliostat which moves with the concentrator (tracking axis 1 and tracking axis 2) as system axes. For perfectly mounted T-type heliostats, *ax1* corresponds to the azimuth (y_{HCS}), and ax2 to the elevation (x_{CCS}) which moves with the rotation around ax1. The axes are not necessarily perpendicular.

Principal Axes Coordinate System (PACS) Special coordinate system which is defined by the principle axes of the oscillations of the heliostat which can be caused by wind forces or other perturbations.

Target Coordinate System (TCS). (x_{TCS}, y_{TCS}, z_{TCS}). Right-handed local coordinate system of a tower mounted target with the *z*-axis being the target normal vector facing the respective heliostat section which uses the target and *x* being the horizontal axis lying in the target plane. For other target shapes (e.g. cylindrical) differing systems using the index TCS can be used.

Mirror Panel. Smallest reflecting or refracting element composing a solar concentrator.

Concentrator. The concentrator is the tracking mirror assembly which reflects the sunlight towards the receiver. It includes the mirror panels and the structural elements supporting them but does not include the pylon, foundation, gears, motors and electronics.

Heliostat. System that reflects the beam solar radiation towards a predetermined fixed target by means of a single or a set of reflecting mirror panels, controlled by a two-axis solar tracking system. The heliostat comprises the whole system, i.e. the concentrator, pylon, foundation, gears, motors, electronics, etc.

Concentrator Surface Normal. Concentrator surface normal vector pointing away from the mirror surface, given in CCS coordinates. The concentrator surface normal is the mirror area weighted mean of the normal vectors of all mirror elements.

Heliostat Normal. The heliostat normal vector is the concentrator surface normal vector, given in HCS or in GCS coordinates.

Heliostat orientation or heliostat alignment. Pair of angles (or vector) describing the orientation of the heliostat normal in the "global" coordinate system of the central receiver system (GCS)

Concentrator Azimuth. Defined to be the angle between the concentrator normal and negative *y*-direction of the GCS (i.e. south direction for northern hemisphere, north direction for southern hemisphere) projected on the horizontal plane. The angle is measured clockwise in the northern hemisphere and anticlockwise in the southern hemisphere. Remark: It is allowed to use negative values (resulting range being between -180° and +180°). Negative values can be transformed to positive values by adding 360° (resulting range being between 0° and +360°).

Concentrator Elevation. Defined to be the angle between the concentrator normal and the horizontal plane of the GCS with mirror surface facing ground being -90°, and mirror surface facing sky +90° elevation. Remark: In the case of a surround field, elevation values larger than 90° may occur during operation, if the elevation axis drive permits this movement. Otherwise, the operating elevation angles usually stay between 0 and 90°, and the "flip-over" is realized by a 180° movement of the azimuth axis.

Canting or Alignment Error. Surface error caused by not perfectly canted or aligned mirror panels on the concentrator.

Contour Error. Surface error given in CCS coordinates and caused by deviations from ideal shape of the mirror panels, e.g. due to the fabrication process, excluding the Canting Error; in the special case of regular repetitive patterns also called waviness error. Contour errors can change with varying gravity, wind, or temperature load.

Specularity or Roughness Error. Surface beam error caused by sub-millimeter structures of the reflective surface. This error is usually measured using the beam spread of the reflective material and can't be resolved by deflectometric, photogrammetric, or laser radar techniques applied to concentrators of industrial size. It reduces the solar weighted spectral reflectance of the concentrator defined for a specific acceptance angle.

Slope Deviation or Slope Error. Surface error given in CCS coordinates and caused by shape deviations of the mirror panels as measured by deflectometry or photogrammetry, for example. It includes all surface errors like contour error, waviness error and canting error, and errors due to gravitational, temperature or wind loads. It does not include the specularity error of the reflective material.

Tracking Deviation or Tracking Error. Deviation of the heliostat true orientation from desired orientation (defined as 1D or 2D-value). The desired orientation is the pre-calculated, ideal orientation of a heliostat. The true orientation is the orientation of a heliostat, approximated by measured orientation of the heliostat normal [Sattler 2020]. The tracking deviation usually is measured on a white target (TCS with unit meter). The values measured in the TCS then have to be transformed to be given in the HCS in mrad. Please note the important notes regarding nomenclature on page 5.

Focus Deviation or Focus Error. The focus deviation is a beam error usually observed on the white target or the receiver. It is given in TCS coordinates. The recommended unit is the length unit “meter”. The focus deviation is twice the value of the tracking error multiplied by the heliostat slant range. More details see page 12.

All Terms and Definitions of Heliostat Performance Parameters. Chapter 5 / Appendix A

Naming Convention for Angular Deviations. The naming in form of a symbol as used in formulas consists of three parts: An abbreviation for the angular deviation as part 1, the information if the value is given for only one dimension (*x*,*y* or *ax1, ax2*) or for 2 dimensions (*2D*) as part 2, and as part 3 the statistical quantity (*MEAN*, *STD*, *RMS*) or an abbreviation of the format of the non-reduced data (*mat*, *vec*). The abbreviation *mat* means that the values behind are a matrix (e.g. for the slope deviations of the mirror surface), *vec* means that it is a vector (e.g. a time series of the tracking error). The recommended standard option 1 uses the order part 1, part 2, part 3. However, it is allowed to put part 3 at the beginning instead at the end, resulting in the order part 3, part 1, part 2.

Part 1	*Surface Error*	*Beam Error*	**Part 2**	**Part 3**
SD	*			
contour	*		*x*	
canting	*		*y*	
…grav	*		x_{CCS}	RMS
…wind	*		y_{CCS}	MEAN
…temp	*		x_{HCS}	STD
Spec		*	y_{HCS}	s_R
BQ		*	x_{TCS}	mat
HQ		*	y_{TCS}	vec
Track	*		2D	σ (*)
Focus		*		
TotHelioDisp		*	ax1	
TotBeamDisp		*	ax2	
astigm		*		

(*) Parameter of circular normal probability density function (see also Appendix A)

Naming Convention for Angular Deviations: Examples

Example	Type of value	Nomenclature Option 1 Part 1-2-3 (standard)	Nomenclature Option 2 Part 3-1-2 (allowed)
Slope Deviation in *x*-dir.	RMS	$SD_{xCCS,RMS}$	$RMS_{SD,xCCS}$
	Standard dev.	$SD_{xCCS,STD}$	σ_{SDxCCS}
	Mean value	$SD_{xCCS,MEAN}$	$MEAN_{SD,xCCS}$
	Matrix values	$SD_{xCCS,mat}$	$mat_{SD,xCCS}$
Tracking Deviation in *y*-dir.	RMS	$Track_{yHCS,RMS}$	$RMS_{Track,yHCS}$
	Standard dev.	$Track_{yHCS,STD}$	$\sigma_{Track,yHCS}$
	Mean value	$Track_{yHCS,MEAN}$	$MEAN_{Track,yHCS}$
	Time series	$Track_{yHCS,vec}$	$vec_{Track,yHCS}$
Beam Quality (always 2D)	RMS	BQ_{RMS}	RMS_{BQ}
	Sigma of circular normal distribution		σ_{BQ}
	Time series	BQ_{vec}	vec_{BQ}

Important notes:

With the slope-deviation SD, the index x_{CCS} / y_{CCS} is frequently abbreviated by *x* or *y*.

With the tracking deviation Track, always the full index must be given. The following nomenclature is defined. If Track is used with the index x_{TCS}, x_{HCS}, or x_{CCS} it must be read as the tracking deviation "in the direction of x_{TCS}, x_{HCS}, or x_{CCS}". If Track is used with an axis (like *ax1*/*ax2* in AS or principle axes of the oscillations PACS), it must be read as the tracking deviation "around the respective axis".

Usually the index used for Track is x_{HCS}. The reason to use x_{HCS} is because it is the performance relevant parameter for the final plant which defines the spillage losses on the target/receiver (HCS as a transferred TCS, *x* horizontal, *y* vertical). If for example *ax1* / *ax2* were used, they would give an insight into the tracking capabilities of each axis, but for heliostats with non-oblique axes for example not necessarily into the heliostat performance on the target/receiver. All statements made for the *x*-direction apply analogously to the *y*-direction.

List of Symbols

Symbol		Unit
Astigm	Astigmatism error (beam error)	mrad
ax1, ax2	Axes of heliostat axis coordinate system (AS)	-
BQ	Beam quality (beam error)	mrad
D	Slant range (betw. the concentrator surface center and beam center)	m
f	Focal length	m
HQ	Heliostat quality error (beam error)	mrad
I	Solar Flux Density	W/m^2
n	number of measurement points	-
Focus	Focus Deviation (beam error on target in TCS)	m
SD	Slope deviation error (surface error)	mrad
Spec	specular or roughness error (beam error)	mrad
TotBeamDisp	Total beam dispersion (beam error)	mrad
TotHelioDisp	Total heliostat dispersion (beam error)	mrad
Track	Tracking error (surface orientation related error)	mrad
T	temperature	°C
t	Time	s
$\bar{u}_{10m}$	10-minute mean wind speed at 10 m height above ground	m/s
x,y,z	Axes of coordinate systems (GCS, TCS, HCS)	-
X,Y,Z	Coordinate of Points	m
z_0	Terrain roughness length	m

List of Symbols – Other

Symbol		
$\overline{\alpha}$	Heliostat elevation angle (mean wind angle of attack)	°
$\overline{\beta}$	Mean wind angle of attack	°
Δ	Difference	
φ	Acceptance Angle	mrad
λ	Wavelength	µm
σ	Parameter of circular normal probability density function (appendix A)	
ρ	Mirror reflectance / Air density	- / kg/m3
Θ_i	Incidence Angle	°
MEAN	Mean value	
RMS	Root mean square value	
STD	Standard deviation (uncorrected sample standard deviation; 1/n)	
STD_{cs}	Standard deviation (corrected sample standard deviation; 1/(n-1))	
s_R	Rayleigh parameter to describe a Rayleigh distribution	
mat	Values stored as matrix	
vec	Values stored as vector	
n	Normal vector	

List of Symbols – Indices

Symbol	
astigm	Optical astigmatism
ax1, ax2	Around first / second rotation axis
az	Azimuth
canting	Canting
conc	Concentrator
contour	Contour
DB	Canonical movement dead band error component
el	Elevation
panel	Mirror panel
grav	Under gravitational load
h	hemispherical
GCS	Global coordinate system of solar power plant
HCS	Heliostat coordinate system (local)
TCS	Target coordinate system (local)
AS	Heliostat axis system (local)
PACS	Principal axes coordinate system (local)
ideal	Ideal value
real	Real or measured value
ref	reference
s	Solar, Solar weighted (actually with ASTM G 173-03)
sum	Sum
sun	Sunshape
temp	Under temperature load
x,y,z	*x*-, *y*-, *z*-component
xy	the product of the two one-dimensional quantities x and y
wind	Under wind load, wind
2D	Combined value (usually *x*-and *y*-direction)

4. Underlying Philosophy of Guideline

4.1 Classification of Parameters

During the last decades, the optical quality of a heliostat has been mainly tested by taking images of its focal spot on a flat, white target. By interpreting the grabbed image using iterative raytracing calculations, global performance parameters have been derived. During the years, shape measurement techniques have been adapted to CSP technology. These shape measurement results describe the quality of the heliostat, independent of conditions like direct irradiation, sunshape, extinction, or position of heliostat, target and sun (hour of the year). They are an objective measure and can be used in modern raytracing tools to get synthetic images of the heliostat on a target at any desired ambient condition, location and setup.

For this reason, the guideline is based on results of shape measurements and not on the approach of flux image interpretation. Parameters describing the dispersion of a heliostat beam on a white target which formerly have been of great importance nowadays can be derived by raytracing simulations and are not essential anymore. Only parameters related to heliostat tracking accuracy are derived using the sun and a white target. Current development in sensors and measurement techniques like accelerators, laser tracker and airborne and tower based optical techniques may also make it possible in the future to derive the tracking parameters independently of the sun and its properties.

There is a variety of former and new parameters which describe heliostat performance. Under consideration of the above said, this guideline has the philosophy to distinguish between essential parameters (class-1), additional descriptive parameters (class-2) and beam parameters (class-3).

The essential parameters (class-1) are mandatory to describe the heliostat performance according to this guideline. In general, all these parameters must be given for comprehensive description of the heliostat performance.

Additional descriptive parameters (class-2) as part of an extended list deliver additional, but not essential information. They may be additionally given.

Beam parameters (class-3) can be derived from class-1 parameters by raytracing, or are not easily measurable under defined conditions in industrial practice. Essential parameters should be preferred to define heliostat performance instead. However, beam parameters can be additionally used for their illustrative character.

In each class, the heliostat parameters are grouped and accordingly named in the following subgroups: Heliostat configuration, optics, tracking, control, limits&tolerances, costs, and O&M:

- Heliostat configuration: Dimensions, geometry of concentrator, mirror panels, support, pedestal
- Optics: Reflectance, heliostat shape and beam properties
- Tracking: Tracking system, accuracy and security
- Control: Control system and power
- Limits & Tolerances: Limits of wind, temperature, hailstone resistance, lifetime, maximum inclinations, etc.
- Costs: Various cost parameters, installation time
- O&M: Power consumptions, consumables, maintenance frequency, etc.

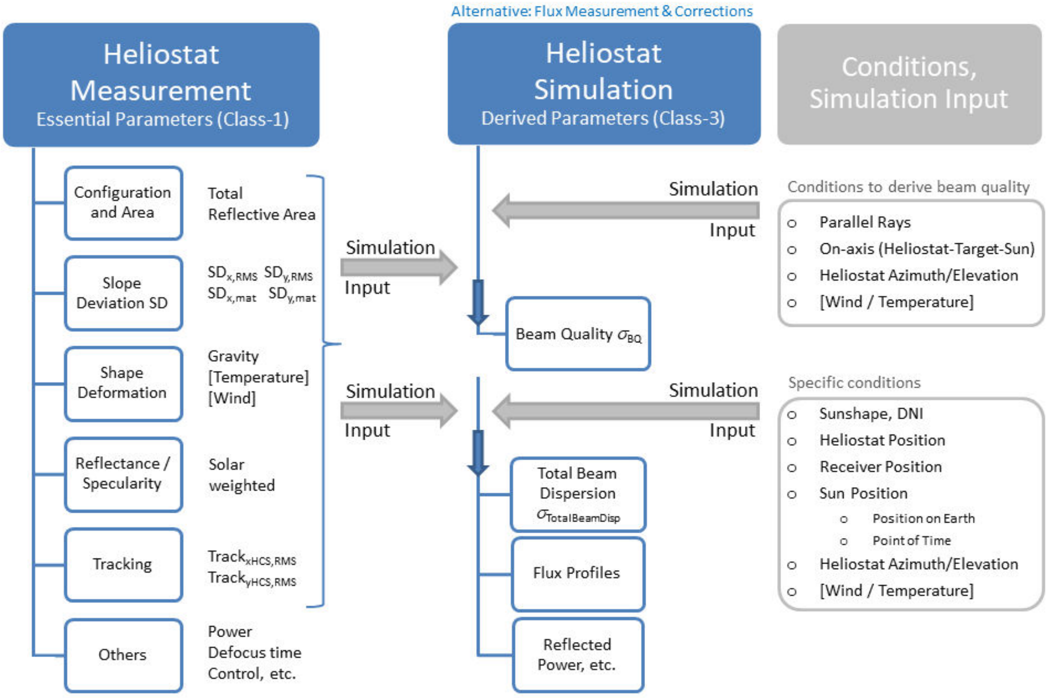

Figure 2: Relation between essential parameters (class-1, left column) and derived parameters (class-3, center column). The right column describes the conditions which must be defined, if class-3 parameters are used (adapted from [Pfahl 2017, Röger 2022]).

Figure 2 shows the relation between essential parameters (left column) and parameters which can be derived by simulation (center column). The essential parameters describe the heliostat performance completely. They include the heliostat configuration, i.e. the heliostat type, the number and location of mirror panels and their reflective area. An ideal heliostat shape has to be defined prior to the calculation of shape deviations. Compared to this defined ideal shape, the slope deviation matrices $SD_{x,mat}$ and $SD_{y,mat}$, given for a reference orientation of the heliostat, describe the heliostat shape accuracy.

Structures deform with gravity depending on the heliostat azimuth ‘az’ and elevation ‘el’, temperature and wind loads. Deformations can be expressed as local changes $\Delta SD_{x/y,mat}$ in the slope deviation entries of the matrices $SD_{x/y,mat}$. The resulting slope deviation matrices $SD_{x,mat,sum}$ and $SD_{y,mat,sum}$ for any heliostat orientation, temperature T and wind load caused by the wind velocity $\bar{u}_{10m}$ can be approximated[1] by:

$$SD_{x/y,mat}^{sum}\left(az, el, \bar{u}_{10m}, \bar{\alpha}, \bar{\beta}, z_0, \rho, T\right) = SD_{x/y,mat}\Big|_{\substack{el,ref\\ az,ref\\ \bar{u}_{10m},ref\approx 0\\ T,ref}} + \Delta SD_{x/y,mat}^{grav}\Big|_{\substack{(el-el,ref)\\ (az-az,ref)}}$$

$$+ \Delta SD_{x/y,mat}^{wind}\Big|_{\substack{\bar{u}_{10m}\\ \bar{\alpha},\bar{\beta}\\ z_0\\ \rho}}$$

[1] For practical reasons of measurement possibilities to derive the temperature influence (measurement at only two differing temperatures), a linear temperature behaviour is formulated in the equation using a gradient [mrad/K]. This approach may be only approximate. Gravitational and wind loads are formulated as absolute changes [mrad] in slope deviation regarding the reference measurement “ref”. Also, it is assumed that there is no correlation between the deformations caused by gravitational, temperature and wind loads.

Index *ref*: reference orientation and temperature at which $SD_{x/ymat}$ is measured (defined in Optics.Conc.Helio RefOrientationTemp), v_{wind} must be negligible during reference measurement.

$$+ \left(\Delta SD_{x/y,mat}^{temp}/\Delta T\right) \cdot \left(T - T_{ref}\right) \quad (1)$$

For this calculation, slope deviation correction matrices for gravitational deflections and deformations due to temperature and wind load must be given. In dimensioning of (glass-mirror) heliostats, gravity loads usually are more significant regarding yearly energy yield, followed by temperature and wind loads. Hence, changes in the slope deviation due to gravity must be given. Deformation matrices to account for temperature and wind loads should be given for heliostats which are susceptible to these loads, e.g. heliostats with sandwich or stretched membrane mirror panels.

Regarding the wind, also the angles of attack of the wind to the concentrator $\overline{\alpha}$ and $\overline{\beta}$, the terrain roughness length z_0 and air density ρ must be specified see [Blume 2023b].

The essential parameters additionally comprise solar weighted reflectance properties of the reflective surface. Due to the large distances between reflector and receiver in central receiver technology compared to parabolic troughs, the specularity of the reflection is of importance. Highly specular solar mirrors must be used. This is described by the two parameters Optics.Reflectance.HighlySpecularMirror and Optics.Reflectance.SolarWeightedSpecular.

Another group of essential parameters describes the heliostat tracking characteristics, like the deviation from its set point (tracking accuracy) or correlation between tracking and time which would lead to tracking offsets during the day. In version 1 of this guideline, the wind related increase of the slope deviation and tracking error [Blume 2020, Blume 2023b] are not yet classified as essential (class-1) parameters, but maybe in future.

Other essential parameters give information about the power type, control system and safety issues like the defocus time in case of receiver emergency or the time into stow position in case of a heavy wind gusts, or wind speed limits.

4.2 Relation between the Essential Shape Parameters, Beam Quality and Total Beam Dispersion

Using the essential parameters of the left column of Figure 2 in a raytracing simulation, we get the Beam Quality (*BQ*). The boundary conditions for the beam quality simulation (right column, top) are an on-axis configuration of sun, heliostat, and target and parallel incident light on the heliostat. In this way, the influence of sunshape and astigmatism do not reflect in the simulated flux map. The specific heliostat orientation and loads of temperature and wind on the heliostat, for which the given beam quality σ_{BQ} is valid, have to be specified.

In order to get the total beam dispersion (*TotBeamDisp*), flux profiles, power peak densities, the reflected power inside a certain radius, etc. another raytracing simulation based on the essential parameters has to be started with the following boundary conditions: real sunshape, DNI, positions of heliostat, receiver and sun, heliostat orientation and load of temperature and wind on the heliostat. This gives the heliostat performance during its specific use in a solar tower power plant configuration. The total beam dispersion is the observed flux distribution during a real-world test while focusing a heliostat on a target. Figure 3 shows a comparison between a raytracing simulation based on deflectometry data and a real flux measurement with four focused heliostats on a white target [Belhomme 2009]. The agreement between the simulated and measured flux distributions is very good.

A mirror or concentrator surface error deviates a reflected sun ray from the desired target point. Two causes lead to the deviation of the reflected ray: Deviation of the local mirror slope (*SD*) from its ideal slope (canting, contour and specular (roughness) errors and errors caused by gravitational, thermal or wind loads) and deviation of the orientation of the whole concentrator from its desired target point (tracking error).

Macroscopic and microscopic imperfections of real mirror surfaces cause a deviation of sun rays reflected off the mirror. The imperfections can be described by the deviation of the actual mirror surface normal vector (n_{real}) from the ideal vector (n_{ideal}) or by the deviation of the actual reflection direction from its ideal direction of an incoming sun beam. The first option leads to figures describing the mirror surface, the latter to figures describing the reflected beam.

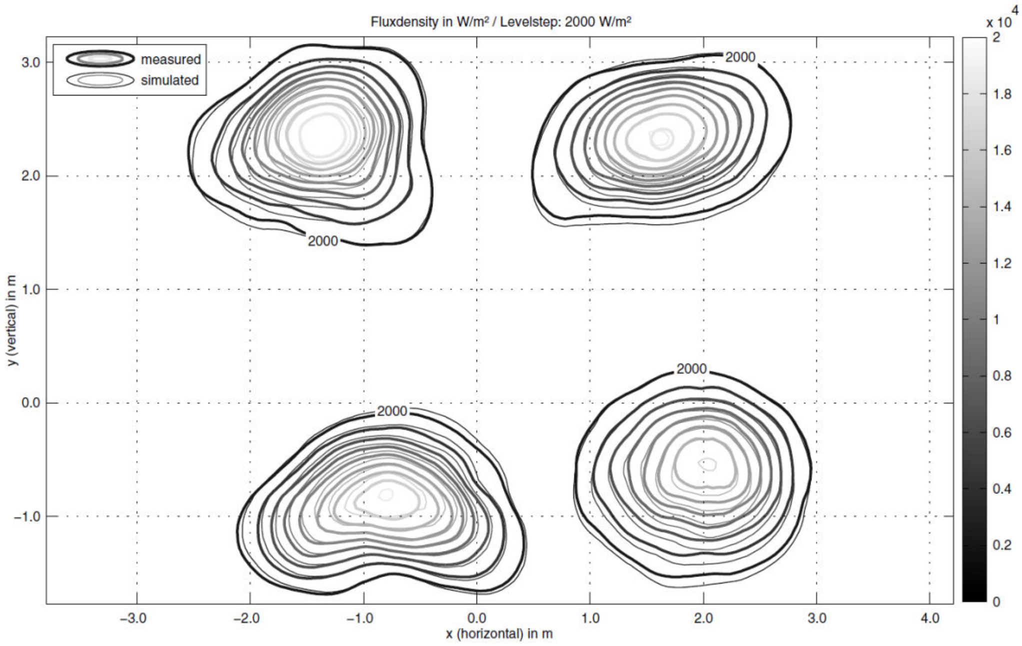

Figure 3: Overlay of measured and simulated beams (raytracing) of four heliostats on a white target [Belhomme 2009].

In all cases, the imperfections can be expressed as angular deviations. The commonly used angular unit is milliradian (mrad). Usually, we find statistical distributions of the angular deviations. A distribution could describe a large number of local mirror slope deviations of one heliostat, the time series of the tracking deviation of a heliostat, or the behavior of a population of heliostats.

In modern raytracers, the spatial distributions of the mirror normal vectors of heliostats can be imported as matrices ($SD_{x,mat}$ and $SD_{y,mat}$) representing the shape in detail and delivering excellent results; see Figure 3. This should be the preferred way of communicating results. However, frequently, reduced statistical values are desired additionally. Reduced data has the advantage to be more intuitive and comparable for humans, can be more easily specified in reports and contracts and need much less storage space and raytracing calculation times. For data reduction, the statistical distribution of angular deviations in one direction (i.e. in x_{CCS} or y_{CCS}-direction like SD_{xCCS} or SD_{yCCS}, for example) often can be approximated by a Gaussian shape and is expressed with its mean value, standard deviation STD, or RMS value. The RMS value can be written as the squared sum of mean value and standard deviation:

$$\mathrm{RMS}_x = \sqrt{\mathrm{MEAN}_x^{\ 2} + STD_x^{\ 2}} \qquad (4)$$

For some quantities, the mean value is zero, so that the RMS value is equivalent to the standard deviation. The statistical distribution of Gaussian normal angular deviations of mirrors in 2D (like SD_{2D}) usually can be described by a Rayleigh distribution with the parameter s_R. Similar is valid to describe the tracking deviation. While $Track_{xHCS}$ and $Track_{yHCS}$ each can be described by RMS, MEAN and STD, $Track_{2D}$ can be better described by a Rayleigh distribution with the parameter s_R if the one-dimensional errors are uncorrelated and normally distributed.

We have to distinguish between surface quantities and beam quantities. Regarding the heliostat movement, the (concentrator) tracking error translates to a (beam) focus deviation/error. Regarding the heliostat shape, the surface error (slope deviation) translates to a beam quality. As between the two errors the ray is reflected on the mirror, the beam quality is twice the value of the surface error. The focus deviation is twice the value of the tracking error multiplied by the heliostat slant range. Table 1 summarizes this relation.

Table 1: Relation between surface and beam errors

Characteristic	Surface error	Beam error	Relation between surface and beam error
Concentrator shape	Slope Error ***SD*** [mrad]	Beam Quality ***BQ*** [mrad]	$BQ = 2 \cdot SD$
Heliostat movement	Tracking Error, or Tracking Deviation ***Track*** [mrad]	Focus Error, or Focus Deviation ***Focus*** [m]	$Focus = 2 \cdot SL \cdot Track$ ** SL: slant range
Heliostat incl. concentrator shape and tracking, w/o sunshape, on-axis*	n/a	Heliostat Quality ***HQ*** [mrad]	n/a
Heliostat incl. concentrator shape and tracking, with sunshape, on-axis*	n/a	Total Heliostat Dispersion ***TotHelioDisp*** [mrad]	n/a
Heliostat incl. concentrator shape, w/o tracking, with sunshape, on-axis*	n/a	Total Beam Dispersion ***TotBeamDisp*** [mrad]	n/a

*on-axis (default), if off-axis, specify!
**This formula is a very good approximation for the small angles occurring in CST systems.

It is preferred to use highly-resolved slope deviation matrices $SD_{x/y,mat}$ to calculate flux maps via raytracing. Statistical values (RMS, MEAN, STD) don't yield the same calculation outputs. The following explanations of statistical values (box) refer to class-3 parameters and are therefore not essential for the correct implementation of the guideline.

The beam errors are listed, requiring a factor of 2 if we come from the surface errors on top. As the specularity error *Spec* is defined as beam error, no factor is necessary there. For glass-silver mirrors, normally, the specularity error can be neglected. The beam quality *BQ* for a specific heliostat orientation, wind and temperature condition can be expressed also in the following formula as a convolution of surface errors, assuming that the errors have nearly normal probability distributions and are statistically independent. The standard deviations in the convolution equation are "sigmas" of a circular normal probability density function [2].

$$\sigma_{BQ} = \sqrt{(2\sigma_{SD})^2 + (\sigma_{Spec})^2}, \text{ or} \quad (5)$$

$$\sigma_{BQ} = \sqrt{\begin{matrix}(2\,\sigma_{SD,contour})^2 + (2\,\sigma_{SD,canting})^2 + (2\,\Delta\sigma_{SD,grav})^2 \\ +(2\,\Delta\sigma_{SD,wind})^2 + (2\,\Delta\sigma_{SD,temp})^2 + (\sigma_{Spec})^2\end{matrix}} \quad (6)$$

Combining distributions of the beam quality of the concentrator (*BQ*) and the focus error of the tracking system (*Focus*) and assuming that these errors have nearly normal probability distributions and are statistically independent, the sigma value of heliostat quality σ_{HQ} can be derived by the added square sum of the individual sigmas power 0.5. For the MEAN value, the two mean values can be added.

The beam quality (*BQ*) and heliostat quality (*HQ*) are derived under parallel incident light. The total dispersion error is larger because the sun is a disk with specific boarder profiles ("sunshapes"). The total beam dispersion (*TotBeamDisp*) and the total heliostat dispersion (*TotHelioDisp*) include the sunshape effect, see bottom of Figure 5. The equations given are only approximations given for the sake of completeness and should not be used, because the sunshape cannot be well approximated by a Gaussian distribution; hence the equation given is only a very rough approximation. Instead, a raytracing or cone-optics modelling software should be used to derive them (see also appendix).

For single heliostats the total beam dispersion *TotBeamDisp* (excl. focus error) is usually given. If the focus is on the solar field performance where several heliostats interact, the total heliostat dispersion *TotHelioDisp* (incl. the focus error) is useful. In any case, while specifying the total beam dispersion, it must be specified for which sunshape and geometrical configuration (on-axis, of off-axis) the heliostat is used.

The beam quality *BQ* both neglects optical aberration (astigmatism) and the influence of the sunshape. The beam quality is related to the total beam dispersion *TotBeamDisp* by the following equation:

$$\sigma_{BQ} \approx \sqrt{(\sigma_{TotBeamDisp})^2 - (\sigma_{Sun})^2} \text{ for on-axis configurations, and} \quad (7)$$

$$\sigma_{BQ} \approx \sqrt{(\sigma_{TotBeamDisp})^2 - (\sigma_{Sun})^2 - (\sigma_{Astigm})^2} \text{ for off-axis configurations.} \quad (8)$$

The total beam dispersion could be measured by analyzing a picture of the focused heliostat beam on a white target. To get the beam quality, sunshape and aberration effects have to be eliminated out of these pictures. This frequently has been done by accompanying raytracing calculations, iteratively varying the slope deviation / beam quality until simulated and measured flux maps coincide, see e.g. [Monterreal 2022].

[2] This is obviously only a fair approximation for the sunshape, specular properties of some mirror materials and some tracking characteristics caused by different accuracies of two tracking axis or non-continuous tracking. For that reason, the guideline does not recommend the use of the convolution equations in the box.

4.3 Selection of Heliostat Samples

Performance testing of a single heliostat means to investigate on a unique sample of a statistical population (whole heliostat field). However, there is variability in the measured properties of the individual heliostats. This section presents some fundamental ideas how to treat this issue.

In practice, frequently there is only one existing prototype to test. This sample should represent the statistical population of a later heliostat field, i.e. using the same manufacturing process, materials, and calibration procedure, etc. If this is not the case, performance test results only describe the heliostat sample tested.

In case several heliostats are available for testing, they should also represent the basic population. To ensure this, an independent sampling strategy should be used by the qualifying research center or company. If this is not possible, or feasible, a remark should be stated in the main measurement report, that the sampling of the heliostat piece was not independent. The parameters generated should be processed in a statistical analysis in the following way:

- The mean value and the standard deviation of the parameters of the heliostats investigated should be given for parameters with dimensions length, area, time, power, weight, forces, moments, percent, etc.
- The root mean square value and the standard deviation of the parameters of the heliostats investigated should be given for parameters which describe angular properties (mrad), i.e. parameters describing the heliostat beam, mirror surface slope and tracking accuracy.

Table 2: Proposed averaging and description of variability shown exemplarily for two types of parameters in the case several heliostats have been tested.

Heliostat no.	Tracking.Safety. EmergDefocusTime in s	Optics.Conc. RealShape_SD_RMS in mrad
1	40.0	1.90
2	41.0	1.64
3	40.5	1.70
4	41.0	1.55
5	41.5	1.69
Result and Variability	40.8 ± 0.6 (MEAN ± STD_{cs})	1.70 ± 0.13 (RMS ± STD_{cs})

MEAN arithmetic mean value
STD_{cs} corrected sample standard deviation
RMS root mean square or quadratic mean

MEAN $$\bar{x} = \frac{1}{n} \sum x_i \qquad (9)$$

STD_{cs} $$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \qquad (10)$$

$$\mathrm{RMS} = \sqrt{\frac{1}{n} \sum x_i^2} \qquad (11)$$

5. Terms and Definitions of Heliostat Performance Parameters

Essential heliostat parameters (class-1) describe the heliostat configuration, optics, tracking, control system, limits and tolerances, and give some rough cost statements. The complete list of essential parameters and their definition is found in Appendix A.1 (page A-1).

The information contained in class-1 parameters is complete regarding two-axis silvered glass mirror-steel heliostats. Appendix A.2 (page A-11) shows a list of the additional descriptive heliostat parameters (class-2). In this extended list, also O&M related parameters are found.

For heliostats other than two-axis silvered glass mirror-steel heliostats, additional information of class-2 parameters are necessary. They are converted to class-1 parameters and must be given. For example,

- Heliostat with stretched membrane technology:
    - O&M.OpPowerConsum.CurvaturePowerConsumMean
    - Optics.Conc.DefWind_deltaSDmat

In the case that a special heliostat may need further essential information, class-2 parameters must be listed in the class-1 category. If the parameter did not exist, the new parameter, its definition, measurement and its value should be given in the report of the heliostat performance testing.

For example, if the heliostat shape is susceptible to temperature changes, that is, if a significant variation of the slope deviation with temperature is observed and hence the class-1 parameter Optics.Conc. DefTemp_deltaSDmat_perK has significant non-zero entries compared to the matrix Optics.Conc.SD_{2D}), the temperature effect should be investigated further. For example, by using the measurement data described in Optics.Conc. DefTemp_deltaSDmat_perK to validate a FEM model, with which different possible load cases and the structural behavior is described. Further, not yet existing, parameters in the category Optics.Conc. may be generated. For example,

- Optics.Conc.DefTempLoadCaseX_deltaSDmat for the change in SD, and
- Optics.Conc.TempLoadCaseX to describe exactly the load case.

In the following, some remarks about class-1 parameters:

Slope Deviations Optics.Conc.$SD_{x/y}$: SD_x, SD_x^* and $SD_x^{HighFraction}$. Although the slope deviation matrices $SD_{x,mat}$ and $SD_{y,mat}$ contain the maximum information and should be used in raytracing, statistical values may be helpful to obtain an overall quality parameter of the slope deviations. While doing statistics, some local slope deviations points lying far away from the average may have significant influence. In order to be able to distinguish an average-quality mirror with a nearly Gaussian distribution of slope errors from a good mirror but in some regions having far higher deviations (e.g. at the mirror panel boarders), three slope deviations are given, here exemplarily written for the *x* direction:

- SD_x: RMS, MEAN and STD for whole measured surface (100%)
- SD_x^*: RMS, MEAN and STD for region of measured surface values *lower than* 3x $SD_{x,RMS}$. In parentheses give the share of region of measured surface values *lower than* 3x $SD_{x,RMS}$ with respect to whole measured region
- $SD_x^{HighFraction}$: RMS, MEAN and STD for region of measured surface values *higher than* 3x $SD_{x,RMS}$. In parentheses give the share of region of measured surface values *higher than* 3x $SD_{x,RMS}$ with respect to whole measured region

Example for SD_x:

- SD_x: RMS: 1.76 MEAN: 0.19 STD: 1.76 (100%)
- SD_x^*: RMS: 1.10 MEAN: 0.00 STD: 1.11 (98%)
- $SD_x^{HighFraction}$: RMS: 9.75 MEAN: 9.75 STD: 0.35 (2%)

In case there are any non-resolved structures, i.e. which are below the measurement resolution (scientist's expertise), then an additional section specifying and discussing the consequences has to be added to the measurement report (parameter Optics.Conc.SD_NonResolvedStruct). It is recommended to repeat the measurement with an enhanced measurement resolution.

In case, a non-measured region may have characteristics which differ from the measured region (scientist's expertise, e.g. the mirror panel boarders), then the influence of these regions on performance / intercept has to be discussed in the measurement report (parameter Optics.Conc.SD_ DiffBetwRegions).

RMS, MEAN, STD, σ: Regarding the 2D slope deviation and tracking parameters SD_{2D} and $Track_{2D}$, only the RMS value is given, while as for the *x*- and *y*-directions all three statistical parameters (RMS, MEAN and STD) are given. Reason is that if the *x*- and *y*-components are uncorrelated and normally distributed with equal variance and zero mean, the 2D statistics of the resulting vectors results in a Rayleigh distribution with parameter $s_R = \sigma$ (which has a MEAN value higher than zero and $s_R \neq$ STD).

If we talk about convolution of errors for the beam quality (Eq. 6 page 13) the "sigmas" describe a <u>circular</u> normal probability density function. In this special case of a circular symmetric distribution, the parameters of all probability density functions are equal, i.e. $\sigma_x=\sigma_y=\sigma= s_R$.

Tracking parameters Tracking.Accuracy.Track. The parameters $Trackx_{xHCS}$ and $Track_{yHCS}$ describe the tracking accuracies for the *x*-component and *y*-component as class-1 performance parameters. During the evaluation of the heliostat images on the target, the focus deviation vector between beam center and aimpoint, given in the target coordinate system (TCS), is transformed to deviations in the heliostat coordinate system (HCS) and to angular deviations using the slant range *SL* (measured between the center of the concentrator surface and the beam center). This procedure delivers a performance indicator independent of the target location/orientation.

In case we are interested in the tracking capabilities of each axis, we can perform a further transformation into the heliostat axis coordinate system (AS), leading to $Track_{ax1}$ and $Track_{ax2}$. This could be done by iterative optimizations of the deviation between simulated and the measured projections of the beam on the target while varying the tracking angles. In guideline version 1, $Track_{ax1}$ and $Track_{ax2}$ are additional (class-2) parameters, because -except for T-type heliostats- they are more difficult to derive and the guideline does not yet give practical assistance. Moreover, they don't directly describe the resulting performance of the tracking properties of the heliostat system as a whole, i.e. not the resulting accuracy of the concentrator orientation.

For further investigations parameters like the tracking correlation between the two axes Tracking_HCS-XYCorrelation (or Tracking_AS-Ax1Ax2Correlation) or the correlation between the axes and time Tracking_HCS-TimeCorrelation (or Tracking_AS-TimeCorrelation) are given. They describe whether there is any correlation between the tracking accuracy of one of the tracking axes with time, or if there is any correlation between the tracking accuracies of the two axes.

The definitions of parameters describing the beam shape are found in Appendix A.3 (page A-18).

6. Determination / Measurement of Heliostat Performance Parameters

Appendix A with its subchapters also describe the determination of the heliostat performance parameters. The values of the parameters can be determined by measurement, simulation, or combined methods.

7. Reporting

The report of a heliostat testing shall comprise the following information.

As header:

- Heliostat manufacturer name
- Exact name of heliostat model
- Serial number or another identifier
- Name and address of testing laboratory
- Testing location
- Date of testing period
- Date of erection of heliostat
- Reference to this guideline with version number of guideline
- Photo or simplified scheme of general heliostat configuration
- If more than one heliostat is measured and the results found in the parameters lists are averaged, the total number of heliostats investigated has to be given.
- In case of multi-dimensional, non-alphanumeric results (e.g. matrices), the type of data carrier (CD, pendrive or link to cloud) has to be specified and delivered

In tabular form:

- All essential parameters (class-1) with the parameter number, full parameter name, measured value and unit
- In case of multi-dimensional, non-alphanumeric results (e.g. matrices), the file location has to be given instead of the measured value.
- For all given parameters, the name of used measurement technique (key word) and/or link to a separate, detailed measurement report and/or reference to another guideline or norm. The detailed measurement report can be a separate document and must describe the measurement technique, used instruments, measurement procedure, data post-processing, repetition of measurements and averaging and measurement accuracy.
- In case of special heliostats, further parameters (from class-2, class-3, or other) must be given with the parameter name, measured value and unit. In case of new parameters, additionally, the parameter definition must be given. Defining new parameters shall only be allowed, if they are not yet listed in the parameter list.
- If more than one heliostat is measured and the results found in the parameters lists are averaged, an additional column has to be attached to give not only the mean value, but also the variability (standard deviation).

Voluntarily, the following information can be given

- Additional heliostat parameters (class-2 and class-3) with the parameter number, full parameter name, measured value, unit, and measurement technique (key word).
- Further information

In graphical form

- Additionally, graphics for visualization should be appended to the report. Especially in the case of multi-dimensional, non-alphanumeric results (e.g. matrices).

An exemplary section of a report is given in Table 3.

Table 3: Example of a heliostat performance test report (excerpt)

HELIOSTAT PERFORMANCE TEST	
Photo or simplified scheme of general heliostat configuration	
Heliostat manufacturer name	HeliostatFactory
Name of heliostat model	Focus
Serial number or other identifier	PX5
Total number of heliostats investigated	1
Name and address of testing laboratory	R&D Testing Center, Street Name, City, Country
Testing location	Heliostat Testing Platform, 52428 Jülich, Germany
Date of testing period	30.04.17 - 30.07.17
Date of erection of heliostat	'01.04.17
Reference to guideline version	SolarPACES Heliostat Performance Guideline v1.0
Report format	This report and data CD
Date, signature and stamp of independent qualification organization	

HELIOSTAT PERFORMANCE TEST – PARAMETERS (excerpt)

n	Full Parameter Name (Symbol)	Value	Unit	Meas.Technique	Measurement Report
	…				
5	HelioConfig.General.Type	T-shape	-	-	-
	…				
25	Optics.Conc.SD_2D	sR: 1.46 RMS 2.06 (100%)	mrad	Deflectometry	MeasRep1.pdf
	…				
35	Optics.Conc.SDmat	2 matrices, see CD	mrad	Deflectometry	MeasRep1.pdf + CD
	…				
59	Cost.SpecificWithout Foundation	80	€/m^2	-	CostReport.pdf

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Appendix A: Heliostat Performance Parameters: Terms/Definitions and Measurement

A.1 Essential Parameters (class-1)

n	Parameter Name (Symbol)	Value Example	Unit	Variable Type	Typical Range	Definition	Technique for Derivation of Parameter	Provided by (Lab/Man)
						HELIOSTAT CONFIGURATION		
1	HelioConfig.CoordinateSys.GCS *GCS*	*(x_{GCS}, y_{GCS}, z_{GCS})*	-	string	-	Please describe the global coordinate system in the measurement report in detail. Usually it is defined like that: Right-handed coordinate system describing positions of tower, receiver and heliostats, with *x* being oriented east, *y* north and *z* vertical up for the northern hemisphere, and *x* being oriented west, *y* south and *z* vertical up. The origin has to be defined. Usually the origin is on the north-south symmetry plane of the solar field at tower ground level, either in the aperture plane of the receiver or in the case of a cylindrical receiver in its central axis at ground level.	-	IQual
2	HelioConfig.CoordinateSys.HCS *HCS*	*(x_{HCS}, y_{HCS}, z_{HCS})*	-	string	-	Please describe the heliostat coordinate system in the measurement report in detail. Usually it is defined like that: Right-handed local cartesian coordinate system defined for each heliostat which does not move with the concentrator movement, with *z* being the vector pointing south for the northern hemisphere (*z* pointing north for the southern hemisphere) or, alternatively, pointing to the tower (must be defined!), and *y* being the vertical axis. The origin could be the intersection of the two tracking axes.	-	IQual
3	HelioConfig.CoordinateSys.CCS *CCS*	*(x_{CCS}, y_{CCS}, z_{CCS})*	-	string	-	Please describe the concentrator coordinate system in the measurement report in detail. Usually it is defined like that: Right-handed local cartesian coordinate system on the concentrator which moves with concentrator elevation and azimuth with *z* being the concentrator surface normal pointing away from the mirror surface and *y* being the vertical axis projected into the concentrator plane (for elevations in the range between 0 and <90°). The origin has to be defined. It should be on the concentrator central axis so that the lowest *z* value of the reflective surface is close to zero and the rest of the *z* values are positive. For other concentrator shapes (e.g. rotation symmetric) differing systems, e.g. polar coordinates, using the index CCS can be used.	-	IQual
4	HelioConfig.CoordinateSys.AS *AS*	*(ax1, ax2)*	-	string	-	Please describe the concentrator coordinate system in the measurement report in detail. Usually it is defined like that: Coordinate system on the heliostat which moves with the concentrator (tracking axis 1 and tracking axis 2) as system axes. For perfectly mounted T-type heliostats, *ax1* corresponds to the azimuth (y_{HCS}), and *ax2* to the elevation (x_{CCS}) which moves with the rotation around ax1. The axes are not necessarily perpendicular.	-	IQual
5	HelioConfig.General.Type	*T-shape*	-	string	-	Construction principle [T-shape / carousel / sloped axes heliostat /steel frame / bubble enclosed / rotating field / ganged heliostats (multiple mirror panels) / venetian blinds / yoke / shared support / dual module drive / etc.]	specified by manufacturer	Man/IQual
6	HelioConfig.Conc.Outline	*rectang.*	-	string	-	Outline of concentrator [rectangular / round / pentagonal / hexagonal / etc.]	specified by manufacturer	Man/IQual
7	HelioConfig.Conc.Dimension	*[6.6; 6.7]*	m	single vector	0 to 100	Concentrator size in [*x*; *y*] direction (rectangular outline) or diameter (round outline) or [min; max] diameter (rotationally symmetric outline) or other description via edge lengths (other outlines)	(Laser) distance meter, tape measure, etc.	Man/IQual
8	HelioConfig.Conc.ReflectiveArea	*40.1*	m²	single	0 to 250	Reflective aperture area of concentrator (excluding gaps between mirror panels)	(Laser) distance meter, tape measure, etc.	Man/IQual
9	HelioConfig.Panel.Outline	*rectang.*	-	string	-	Outline of reflective mirror panel [rectangular / round / triangular / pentagonal / hexagonal / etc.]	specified by manufacturer	Man/IQual

10	HelioConfig.Panel.Dimension	*[3.0; 1.1]*	m	single vector	0 to 100	Mirror panel size in [*x*; *y*] direction (rectangular outline) or diameter (round outline) or [min; max] diameter (rotationally symmetric outline) or [*a*;*b*;*c*;...] edge lengths (triangular and other outlines); if necessary describe values further	(Laser) distance meter, tape measure, etc.	Man/IQual
11	HelioConfig.Panel.Number	*[2; 6]*	-	integer vector	0 to 100	Number of mounted mirror panels per concentrator [n_x; n_y] (rectangular conc. outline) or [*n*] (rotationally symmetric conc. outline) or [n_i;n_o] (rotationally symmetric conc. outline with inner (*i*) and outer ring (*o*)) or similar. Alternatively, in case of rectangular outline and missing mirror panels (e.g. in the pedestal regions), a binary information vector can be given, putting the prefix "bin" in front of the vector. In the binary vector, each binary number corresponds to a mirror facet row. The binary number for one mirror panel row is the binary sum of the bits, while the bit is 0 for a missing facet and 1 for a mounted mirror panel. For example: " bin [63; 63; 51; 51] would represent a heliostat with 4 horizonal mirror panel rows and 6 vertical mirror panels, while in the two lower rows, the two center mirror panels are missing in each row (due to the pedestal).	specified by manufacturer	Man/IQual
12	HelioConfig.Panel.Type	*glass mirror panels*	-	string	-	Reflective surface type [glass mirror panels / stretched steel membrane / sandwich mirror panels etc.]	specified by manufacturer	Man/IQual
13	HelioConfig.Panel.Material	*silver coated glass*	-	string	-	Reflective surface material [silver coated glass / silver coated thin glass / aluminum / aluminized mylar / coated or laminated polymer foil / etc.]	specified by manufacturer	Man/IQual
14	HelioConfig.Axes.Alignment	[az. axis vert.; el. axis horiz.]	-	string	-	Orientation of the [first; second] tracking axis while the second axis is defined as the one which moves with the first axis. e.g. [azimuth axis vertical; elevation axis horizontal / inclined to horizon 20° or interval 20 to 40° / equatorial mounting / English mounting, etc.]	specified by manufacturer	Man/IQual
15	HelioConfig.Axes. HeightOfSecondaryAxis	*2.14*	m	single	0 to 100	Height of center of secondary axis (mostly elevation axis) from ground	(Laser) distance meter, tape measure, etc.	Man/IQual
16	HelioConfig.Axes.DistanceAx1Ax2	*0.15*				Distance of first and second tracking axis	(Laser) distance meter, tape measure, etc.	Man/IQual
17	HelioConfig.Axes. DistanceConcToSecondaryAxis	*0.10*	m	single	0 to 5	Distance from the concentrator vertex to the second tracking axis. This is often approximately the length of the cantilever arm between the central line of the horizontal elevation axis and the mirror plane (=reflecting plane)	(Laser) distance meter, tape measure, etc.	Man/IQual
						HELIOSTAT OPTICS		
18	Optics.Panel.CurvatureMounted	*flat*	-	string	-	Design target curvature of mirror panel after mounting [flat / parabolic / spherical / etc.]	specified by manufacturer	Man
19	Optics.Panel.CurvatureMethod	*tensionless*	-	string	-	Method of curvature [tensionless (use of pre-curved or flat mirror panels) / fixed to curved support structure / depression (pneumatic) / etc.]	specified by manufacturer	Man
20	Optics.Conc.NominalShape	*parabolic*	-	string	-	Design target curvature shape of complete concentrator including canting information [flat / parabolic / spherical / special heliostat canting (if e.g. yearly energy output computer-optimized canting)]. Numeric values are given in Optics.Conc.NominalShapeNumericValue.	specified by manufacturer	Man
21	Optics.Conc. NominalShapeNumericValue	*[55] or [25;1500] or matrices*	m	single vector, matrix	0 to 9999 or NaN (flat)	Design target curvature radius in case of spherical, focal length in case of parabolic, NaN in case of flat; for a conc. with adjustable focus give [min; max] range; for special heliostat canting ideal shape should be described by matrices *x*[m;n], *y*[m;n], *z*[m;n]	specified by manufacturer	Man
22	Optics.Conc. HelioRefOrientationTemp	*[az=0°; el=30°; T=20°C]*	-	string	-	Azimuth / elevation angle and heliostat temperature for which the SD data is valid; measurement without significant wind influences. In case, there are no limitations, [*az*=0°; *el*=30°; *T*~20°C] should be used. In case azimuth angle has no influence of shape (standard T-heliostat), the azimuth value can be omitted.	Inclinometer, protractor	IQual

23	Optics.Conc.SD_SamplingRate	*1000*	value s/m2	single	>100	Average sampling Rate used for the slope deviation measurement. Must be higher than 100 data points/m2.	Divide total number of measurement points by total measured surface; the measurement should be homogeneously distributed on the measured surface	IQual
24	Optics.Conc.SD_ShareEvalSurf	*97*	%	single	95-100%	Share of evaluated surface of total reflective surface; must be higher than 95%.	Area in which the surface error is evaluated (see Optics.Conc.SD_2D) divided by total HelioConfig.Conc.ReflectiveArea	IQual
25	Optics.Conc.SD_2D SD_{2D}	sR: 1.46 RMS: 2.06 (100%)	mrad	string	<3 mrad	Rayleigh Parameter sR and RMS for 2D slope deviations of real concentrator compared to surface generated using the Optics.Conc.NominalShape for whole measured surface, applying over the whole heliostat surface a ROBUST least squares optimization for the orientation of measured data to the nominal geometry. Minimum recommend resolution 100 data points/m2; minimum evaluated surface (> 95%); Low wind speeds (<NormalOperation) and no excessive temperature gradients. The measurement uncertainty of the slope deviation-RMS value has to be given (should be below 0.2 mrad). Definition of slope deviations, see SolarPACES draft guideline "Measurement and Assessment of Mirror Shape for Concentrating Solar Collectors". Give values for whole measured surface. Write in parentheses "100%", that means that all measured values (not necessarily whole reflective surface) are considered for the RMS (sR) value. Coordinate System: CCS.	The heliostat surface slopes can be measured directly by deflectometry or by measuring 3-D coordinates of the heliostat surface, using photogrammetry, laser radars, etc. While deflectometry directly gives slopes as a result, the 3-D measurement technique results have to be processed via tringualation and calculation of normal vectors. Slope deviations are calculated in reference to the nominal normal vectors defined in parameters Optics.Conc.NominalShape and Optics.Conc.NominalShapeNumericValue while orienting the two data clouds with a ROBUST least square method or similar. The minimum recommend resolution is 100 data points/m2 for photogrammetry, the other techniques should use their potential for higher resolution. The minimum evaluated surface must be higher than > 95% of the heliostat surface. The measurement uncertainty of the slope deviation matrix entries has to be given. Locally, they should be below 0.5 mrad. The uncertainties for the RMS of the slope deviation of the whole concentrator should be below 0.2 mrad. A separate measurement report must be created where all the necessary details of the measurement procedure, evaluation and accuracies is given. Note: $SD_{2D,sR}$=1/sqrt(2)*$SD_{2D,RMS}$. Note: The parameter $SD_{2D,RMS}$ can be approximated by the *x*- and *y*-component of the slope deviation (Optics.Conc.SDx and Optics.Conc.SDy): $SD_{2D,RMS} = (SD_{x,RMS}^2 + SD_{y,RMS}^2)^{0.5}$. However, more precise is to combine the individual vectors dx and dy to 2D vector deviations and then apply the statistics.	IQual
26	Optics.Conc.SD_2D* SD_{2D}^*	sR: 1.09 RMS: 1.54 (98%)	mrad	string	<3 mrad	Rayleigh Parameter sR and RMS for 2D slope deviations of real concentrator compared to Optics.Conc.NominalShape for region of measured surface values lower than 3x$SD_{RMS,2D}$ (3x$SD_{2D,sR}$), applying over the whole heliostat surface a ROBUST least squares optimization for the orientation of measured data to the nominal geometry. Minimum recommend resolution 100 data points/m2; minimum evaluated surface (> 95%); Low wind speeds (<NormalOperation) and no excessive temperature gradients. The measurement uncertainty of the slope deviation-RMS value has to be given (should be below 0.2 mrad). Definition of slope deviations, see SolarPACES draft guideline "Measurement and Assessment of Mirror Shape for Concentrating Solar Collectors". Give values for region of measured surface values lower than 3x$SD_{2D,RMS}$ (3x$SD_{2D,sR}$). In parentheses give the share of region of measured surface values lower than 3x$SD_{2D,RMS}$ (3x$SD_{2D,sR}$) with respect to whole measured region. Coordinate System: CCS.	From the heliostat surface slope measurement (see explications of Optics.Conc.SD_{2D}), only the region is considered where the measured surface values are lower than 3x$SD_{RMS,2D}$. The derivation of this value is done in the following steps: 1. Exclude all local slope deviations values being higher than 3x$SD_{RMS,2D}$. 2. Calculate RMS value for the remaining measured heliostat surface (<3x$SD_{RMS,2D}$). This is the (*)-value Optics.Conc.SD_{2D^*} 3. Calculate the share of the region of measured surface values being lower than 3x$SD_{RMS,2D}$ respect to whole measured region. Note: $SD_{2D^*,sR}$=1/sqrt(2)*$SD_{2D^*,RMS}$. Note: The parameter $SD_{2D^*,RMS}$ can be approximated by the *x*- and *y*-component of the slope deviation (Optics.Conc.SD_{x^*} and Optics.Conc.SD_{y^*}): $SD_{2D^*,RMS} = (SD_{x,RMS^*}^2 + SD_{y,RMS^*}^2)^{0.5}$	IQual
27	Optics.Conc.SD_2DHighFraction $SD_{2D}^{HighFraction}$	sR: 6.95 RMS: 9.83 (2%)	mrad	string	<20 mrad	Rayleigh Parameter sR and RMS for 2D slope deviations of real concentrator compared to Optics.Conc.NominalShape for region of measured surface values higher than 3x$SD_{RMS,2D}$ (3x$SD_{2D,sR}$), applying over the whole heliostat surface a ROBUST least squares optimization for the orientation of measured data to the nominal geometry. Minimum recommend resolution 100 data points/m2; minimum evaluated surface (> 95%); Low wind speeds (<NormalOperation) and no excessive temperature gradients. The measurement uncertainty of the slope deviation-RMS	From the heliostat surface slope measurement (see explications of Optics.Conc.SD_2D), only the region is considered where the measured surface values are higher than 3x$SD_{RMS,2D}$. The derivation of this value is done in the following steps: 1. Exclude all local slope deviations values being lower than 3x$SD_{RMS,2D}$.	IQual

						value has to be given (should be below 0.2 mrad). Definition of slope deviations, see SolarPACES draft guideline "Measurement and Assessment of Mirror Shape for Concentrating Solar Collectors". Give values for region of measured surface values higher than $3xSD_{2D,RMS}$ ($3xSD_{2D,sR}$). In parentheses give the share of region of measured surface values higher than $3xSD_{2D,RMS}$ ($3xSD_{2D,sR}$) with respect to whole measured region. Coordinate System: CCS.	2. Calculate RMS value for the remaining measured heliostat surface (>$3xSD_{RMS,2D}$). This is the high fraction value Optics.Conc.SD_2DHighFraction 3. Calculate the share of the region of measured surface values being higher than $3xSD_{RMS,2D}$ respect to whole measured region.	
28	Optics.Conc.SDx /SDrad SD_x *(or* SD_{rad}*)*	RMS: 1.76 MEAN: 0.19 STD: 1.76 (100%)	mrad	string	<3 mrad	RMS, mean and standard deviation for slope deviations in horizontal direction (*x*) of real concentrator to the Optics.Conc.NominalShape for whole measured surface, applying over the whole heliostat surface a ROBUST least squares optimization for the orientation of measured data to the nominal geometry. Minimum recommend resolution 100 data points/m2; minimum evaluated surface (> 95%). Low wind speeds (<NormalOperation) and no excessive temperature gradients. If rotation-symmetric concentrator, give SD_{radial} (SD_{rad}) instead of SD_x. The measurement uncertainties of the slope deviation-RMS/MEAN/STD values have to be given (should be below 0.2 mrad). Definition of slope deviations, see SolarPACES draft guideline "Measurement and Assessment of Mirror Shape for Concentrating Solar Collectors". Give, RMS, MEAN and STD for whole measured surface. Write in parentheses "100%", that means that all measured values (not necessarily whole reflective surface) are considered. Coordinate System: CCS.	see Optics.Conc.SD_2D	IQual
29	Optics.Conc.SDx* /SDrad* SD_x* *(or* SD_{rad}**)*	RMS: 1.10 MEAN: 0.00 STD: 1.11 (98%)	mrad	string	<3 mrad	RMS, mean and standard deviation for slope deviations in horizontal direction (*x*) of real concentrator to the Optics.Conc.NominalShape for region of measured surface values lower than $3xSD_{x,RMS}$, applying over the whole heliostat surface a ROBUST least squares optimization for the orientation of measured data to the nominal geometry. Minimum recommend resolution 100 data points/m2; minimum evaluated surface (> 95%). Low wind speeds (<NormalOperation) and no excessive temperature gradients. If rotation-symmetric concentrator, give SD_{radial} (SD_{rad}) instead of SD_x. The measurement uncertainties of the slope deviation-RMS/MEAN/STD values have to be given (should be below 0.2 mrad). The measurement uncertainty should be below 0.5 mrad. Definition of slope deviations, see SolarPACES draft guideline "Measurement and Assessment of Mirror Shape for Concentrating Solar Collectors". Give, RMS, MEAN and STD for region of measured surface values lower than $3xSD_{x,RMS}$. In parentheses give the share of region of measured surface values lower than $3xSD_{x,RMS}$ with respect to whole measured region. Coordinate System: CCS.	see Optics.Conc.SD_2D*	IQual
30	Optics.Conc.SDxHighFraction/ SDradHighFraction $SD_x^{HighFraction}$ *(or* $SD_{rad}^{HighFraction}$*)*	RMS: 9.75 MEAN: 9.75 STD: 0.35 (2%)	mrad	string	<20 mrad	RMS, mean and standard deviation for slope deviations in horizontal direction (*x*) of real concentrator to the Optics.Conc.NominalShape for region of measured surface values higher than $3xSD_{x,RMS}$, applying over the whole heliostat surface a ROBUST least squares optimization for the orientation of measured data to the nominal geometry. Minimum recommend resolution 100 data points/m2; minimum evaluated surface (> 95%). Low wind speeds (<NormalOperation) and no excessive temperature gradients. If rotation-symmetric concentrator, give SD_{radial} (SD_{rad}) instead of SD_x. The measurement uncertainties of the slope deviation-RMS/MEAN/STD values have to be given (should be below 0.2 mrad). Definition of slope deviations, see SolarPACES draft guideline "Measurement and Assessment of Mirror Shape for Concentrating Solar Collectors". Give, RMS, MEAN and STD for region of measured surface values higher than $3x_{SDx,RMS}$. In parentheses give the share of region of measured surface values higher than $3xSD_{x,RMS}$ with respect to whole measured region. Coordinate System: CCS.	see Optics.Conc.SD_2DHighFraction	IQual
31	Optics.Conc.SDy /SDtan SD_y *(or* SD_{tan}*)*	RMS: 1.08 MEAN: -0.03 STD: 1.09 (100%)	mrad	string	<3 mrad	see Optics.Conc.SDx / SDrad, replacing *x* by *y*, *radial* or *rad* by *tangential* or *tan*	see Optics.Conc.SD_2D	IQual

32	Optics.Conc.SDy* /SDtan* *SD_y* (or SD_{tan}*)*	RMS: 1.08 MEAN: -0.03 STD: 1.09 (100%)	mrad	string	<3 mrad	see Optics.Conc.SDx* / SDrad*, replacing *x* by *y*, *radial* or *rad* by *tangential* or *tan*	see Optics.Conc.SD_2D*	IQual
33	Optics.Conc.SDyHighFraction / SDtanHighFraction *$SD_y^{HighFraction}$ (or $SD_{tan}^{HighFraction}$)*	RMS: - MEAN: - STD: - (0%)	mrad	string	<20 mrad	see Optics.Conc.SDxHighFraction / SDradHighFraction, replacing *x* by *y*, *radial* or *rad* by *tangential* or *tan*	see Optics.Conc.SD_2DHighFraction	IQual
34	Optics.Conc.SD_NonGaussianDistr	No	-	string	Yes/no	Is the frequency distribution of the local slope deviation strongly non-Gaussian (scientist's expertise)? - If yes, the measured slope deviation matrices $SD_{x,mat}$ and $SD_{y,mat}$ containing the local data local slope deviation maps (parameter Optics.Conc.SDmat) and histograms MUST be given in the (digital) reports and graphics.	see Optics.Conc.SD_2D	IQual
35	Optics.Conc.SDmat *$SD_{x,mat}$ and $SD_{y,mat}$* *(or $SD_{tan,mat}$ and $SD_{rad,mat}$)*	*2 matrices, see CD*	mrad	matrices	<20 mrad	Two matrices of local slope deviation maps $SD_{x,mat}$ ($SD_{y,mat}$) in horizontal (vertical) direction *x* (*y*) of the real concentrator compared to the surface generated using the Optics.Conc.NominalShape for the whole measured surface, applying over the whole heliostat surface a ROBUST least squares optimization for the orientation of measured data to the nominal geometry. Minimum recommend resolution 100 data points/m2; minimum evaluated surface (> 95%). Low wind speeds (<NormalOperation) and no excessive temperature gradients. If rotation-symmetric concentrator, give SD_{radial} (SD_{rad}) instead of SD_x ($SD_{tangential}$ (circumferential) (SD_{tan}) instead of SD_y). The measurement uncertainty of the slope deviation matrix entries has to be given (should be below 0.5 mrad). Definition of slope deviations, see SolarPACES draft guideline "Measurement and Assessment of Mirror Shape for Concentrating Solar Collectors". Coordinate System: CCS.	see Optics.Conc.SD_2D	IQual
36	Optics.Conc.SD_NonResolvedStruct	No	-	string	Yes/no	Are there are non-resolved structures, i.e. which are below the measurement resolution (scientist's expertise)? If yes, specify in text form and discuss consequences in separate document. It is recommended to repeat measurement with enhanced measurement resolution.	Visual inspection	IQual
37	Optics.Conc.SD_DiffBetwRegions	No	-	string	Yes/no	Has the non-measured region characteristics which differ from the measured region (scientist's expertise)? If yes, discuss influence of these regions on performance / intercept in separate document.	Visual inspection	IQual
38	Optics.Conc.DefGravity_dxdydz *5x dx_{mat}^{grav}, 5x dy_{mat}^{grav}, 5x dz_{mat}^{grav}* and orientation vector	*5 times; 3x[m;n] matrix*	mm	matrix	0 to 50	Heliostat deformation due to gravity: at least 5 times 3 [*m*,*n*]-matrices and vector with the heliostat elevation angles (e.g. 0 30 45 60 90°): for each heliostat elevation angle give the shape deformation of the point cloud: *dx*[*m*;*n*], *dy*[*m*;*n*], *dz*[*m*;*n*]. The shape deformation is zero for the conditions defined in Optics.Conc.HelioRefOrientationTemp. The elevation should cover the whole elevation working angles; interpolation is used to get values for other elevation angles. For slope deviation values calculated from these deformation matrices, see Optics.Conc.DefGravity_deltaSDmat. Coordinate System: CCS.	The heliostat deformation is preferably measured by photogrammetry. Also, other 3-D measurement techniques as e.g. laser radars could be used. If this is not possible, FEM simulations may provide the results, with the drawback of the uncertainty of modeling errors. The point-based measurement uncertainty for the entire measurement volume should be within 0.05 mm + 0.025 mm/m with respect to the largest object dimension (1 sigma). This leads to 0.3 mm for a 10 m x 10 m heliostat (100 m²) resp. 0.4 mm for a 14 m x 14 m heliostat (200 m²). For deformation investigations required here, the resolution can be lower compared to shape measurements. For deformation analysis, a resolution by one order of magnitude lower than the slope deviation measurements is typically sufficient (e.g. 5-10 targets/m2 for simple structures). A locally higher resolution of targets (about every 100 mm) is recommended for more complex structures. The following rules of thumb may be applied: GENERAL: Apply the outer targets as close as possible to the mirror borders and distribute the other targets in the following way: FOR HELIOSTATS WITH MIRROR SUPPORT POINTS: Apply targets at all mirror support point locations and apply twice as many targets as number of support points in *x*-direction; the same in *y*-direction. Then, apply targets at the mirror edges. Depending	IQual

						on mirror design and mirror support structure, a higher resolution might be required, or a lower be sufficient. A measurement accuracy quality check should be made using calibration bars attached at the heliostat boarders in the two dimensions of the heliostat surface in case of photogrammetry. A separate measurement report must be created where all the necessary details of the measurement procedure, evaluation and accuracies is given. From these 3-D measurement results, shape deviations are generated by subtracting from all matrices the shape measured (or interpolated) for the heliostat orientation documented in Optics.Conc.HelioRefOrientationTemp. Before subtracting, the two data clouds are oriented with a ROBUST least square method or similar.	
39	Optics.Conc.DefTemp_dxdydz_perK $(dx_{mat}^{temp})/dT$, $(dy_{mat}^{temp})/dT$, $(dz_{mat}^{temp})/dT$	*3x[m;n] matrix*	mm/K	matrix	0 to 50	Heliostat deformation due to temperature loads: 3 [*m*,*n*]-matrices: *dx*/*dT*[*m*;*n*], *dy*/*dT*[*m*;*n*], *dz*/*dT*[*m*;*n*] containing the concentrator deformation in mm per Kelvin temperature difference [mm/K], determined around a mean operation temperature. This parameter is tolerated exceptionally to be void for conventional glass-steel heliostats. It must be given for composite materials like e.g. sandwich mirror panels. For slope deviation values calculated from these deformation matrices, see Optics.Conc.DefTemp_deltaSDmat. Coordinate System: CCS.	Two shape measurements at different temperatures at the elevation angle given in the parameter Optics.Conc.HelioRefOrientationTemp are performed and the change in shape per Kelvin ambient temperature is given for both dimensions using e.g. photogrammetry (see also Optics.Conc.DefGravity_dxdydz). Any possible blocked radiation on backside from other heliostats or other local energy input must be avoided. Time of the day with strong temperature transients should be avoided, e.g. one measurement at the end of the night and one at the end of the day is preferred. In addition to the ambient temperature measurements during the two shape measurements, the mean temperature of the mirror surface and the mean temperature of the heliostat structure, mostly steel, should be reported in the measurement report.	IQual
40	Optics.Conc.DefGravity_deltaSDmat 5x $\Delta SD_{x,mat}^{grav}$, 5x $\Delta SD_{y,mat}^{grav}$ and orientation vector *(or 5x* $\Delta SD_{tan,mat}^{grav}$, *5x* $\Delta SD_{rad,mat}^{grav}$ and orientation vector)	*5 x 2 matrices and elevation vector, see CD*	mrad	matrices and single vector	<20 mrad	Heliostat deformation due to gravity expressed as change in surface slope error: 2x5 matrices containing change in slope deviation in mrad with respect to reference orientation (defined in Optics.Conc.HelioRefOrientationTemp) for both directions for 5 heliostat elevation angles covering the whole operational angle range. The 5 heliostat elevation angles are given as a vector, (e.g. *el*=[0 30 45 60 90]°, or depending on operational range of heliostats in later solar plant). Example: $\Delta SD_{x,mat}^{grav}$ |(el_1 -el_{ref}), $\Delta SD_{x,mat}^{grav}$ |(el_2-el_{ref}), ... , $\Delta SD_{x,mat}^{grav}$ |(el_5-el_{ref}) and *el*=[el_1; el_2; ...; el_5]; *y*-direction similar. Coordinate System: CCS.	From the shape deviation matrices due to gravity (parameters Optics.Conc.DefGravity_dxdydz dx_{mat}^{grav}, dy_{mat}^{grav}, dz_{mat}^{grav}), slope deviation matrices describing the SD increase due to gravity are generated by triangulation and calculation of normal vectors. In special cases, not only photogrammetry or laser trackers, but also deflectometry may be applicable to measure the slope deviation matrices. During its use, these deformation matrices are added to the matrices in Optics.Conc.SDx/y to get the final slope deviation matrices to model the respective gravity load of the heliostat as function of the elevation angle in the raytracing software.	IQual
41	Optics.Conc. DefTemp_deltaSDmat_perK $(\Delta SD_{x,mat}^{temp})/dT$, $(\Delta SD_{y,mat}^{temp})/dT$ *or* $(DSD_{tan,mat}^{temp}/dT)$,$(\Delta SD_{rad,mat}^{temp}/dT)$	*2 matrices, see CD*	mrad /K	matrices	<5 mrad/K	Heliostat deformation due to temperature loads expressed as change in surface slope error per K temperature change: 2 matrices containing the concentrator deformation in mrad per Kelvin ambient temperature difference [mrad/K] for both directions, determined around a mean operation temperature. This parameter is tolerated exceptionally to be void for conventional glass-steel heliostats. It must be given for composite materials like e.g. sandwich mirror panels. The orientation of the heliostat should correspond to a common operating condition which is in the middle of the total heliostat operating range, e.g. *az*=0°, *el*=40°. In any case, it must be given in the measurement report. Coordinate System: CCS.	From the shape deviation matrices due to temperature change (parameters Optics.Conc.DefTemp_dxdydz_perK $(dx_{mat}^{temp})/dT$, $(dy_{mat}^{temp})/dT$, $(dz_{mat}^{temp})/dT$), slope deviation matrices describing the SD increase due to temperature loads are generated by triangulation and calculation of normal vectors. In special cases, not only photogrammetry or laser trackers, but also deflectometry may be applicable to measure the slope deviation matrices. During its use, these deformation matrices are added to the matrices in Optics.Conc.SDx/y to get the final slope deviation matrices to model the respective temperature load of the heliostat in the raytracing software.	IQual
42	Optics.Reflectance. SolarWeightedSpecular $\rho_{s,\varphi}$([320;2500], Θ_i<=15°, φ)	*95.0*	%	single	80 to 100	Solar weighted spectral reflectance for incidence angles <=15°; determined according to the SolarPACES reflectance guideline (version 3.1 or higher). Note: Central receiver systems usually require small reflection cones of 1-2 mrad. Hence highly specular solar mirrors must be used. The solar weighted spectral reflectance	If the parameter Optics.Reflectance.HighlySpecularMirror is "yes" (i.e. a highly specular solar mirror is used), then the solar weighted specular reflectance (Optics.Reflectance.SolarWeightedSpecular) can be approximated by the solar weighted hemispherical	Man/IQual (indoor measurement)

						is influenced by sub-millimeter structures of the reflective surface (which is also called roughness error).	reflectance $\rho_{s,h}$([320;2500], Θ_i <=15°,h) which can be measured with a spectrophotometer measurement (lab).	
43	Optics.Reflectance. HighlySpecularMirror	*Yes*	-	string	Yes/no	Is the solar mirror highly specular according to the SolarPACES reflectance guideline (version 3.1 or higher) AND the simplified procedure of the reflectance guideline was used, assuming that the solar weighted spectral reflectance can be approximated by the solar weighted hemispherical reflectance?	You can do examinations according to the SolarPACES reflectance guideline (see appendix A of reflectance guideline) to check if highly specular solar mirrors are used. If positive, a spectrophotometer measurement (lab) can measure the solar weighted hemispherical reflectance and the parameter Optics.Reflectance.SolarWeightedSpecular can be approximated by the solar weighted hemispherical reflectance value.	
44	Optics.Focus.Variability	*fix focal length*	-	string	-	Ways to adjust focal length during operation [fix focal length / adjustable: mechanically (rear-membrane-pull), depression (blower), ... / etc.]	specified by manufacturer	IQual/Man
						HELIOSTAT TRACKING		
45	Tracking.Axes.Concept	[el.motor/ gear drive; el.motor/gear drive]	-	string	-	General tracking and drive concept of [first; second] rotation axis; [electric motor + gear drive / stepper motor / magnetic / hydraulic / gravitational (using water) / etc.]	specified by manufacturer	Man
46	Tracking.Axes.Control	[closed loop; closed loop]	-	string	-	Tracking control method or practice for [first; second] tracking axis; [none=using sun algorithm / closed loop / open loop / vision based / using the sun / ... etc.] combinations of features are allowed.	specified by manufacturer	Man
47	Tracking.Axes.MinMaxRangeAxis1	[-80; 80]	°	single vector	0 to 360	[min; max] angle range of the concentrator orientation for first rotation axis	Inclinometer, protractor	IQual/Man
48	Tracking.Axes.MinMaxRangeAxis2	[-180; 180]	°	single vector	0 to 360	[min; max] angle range of the concentrator orientation for second rotation axis	Inclinometer, protractor	IQual/Man
49	Tracking.Axes. TimetoMoveMinMaxRange	[360; 300]	s	single vector	60 to 600	[TimeAxis1; TimeAxis2]; First value: Time to move around the whole range of axis1 from min to max, as defined in MinMaxRangeAxis1. Second value: Time to move around the whole range of axis2 from min to max, as defined in MinMaxRangeAxis2. Time is measured from first real movement (excluding reaction time)	Electronic time clock; Move heliostat to min axis position. Start of time measurement when heliostat reacts. Stop time when heliostat has been reached the max position. Use inclinometer or protractor, for example.	IQual/Man
50	Tracking.Accuracy. TrackingTestConditions	[az_{min}=-30°; az_{max}=+30°; el_{min}=20°; el_{max}=65°; T=20°C; v_{Wind}=2m/s]	-	string	-	Description of the testing conditions during the tracking tests from which all Tracking.Accuracy parameters are derived: Give the range of heliostat azimuth and elevation angles during the tests, together with the mean ambient temperature and the mean wind speed. The angles should cover as large an area as possible.	Inclinometer or protractor, temperature measurement device, Anemometer for wind speed @ 10m.	IQual
51	Tracking.Accuracy.Track_2D_HCS $Track_{2D,HCS}$	sR: 0.75 RMS: 1.06	mrad	string	<2 mrad	Rayleigh Parameter sR and RMS of 2D tracking accuracy, determined by a continuous position measurement of the beam center during the course of a day for sun elevations over 10 degrees with a sampling rate of 1 per minute or higher for wind speeds in the range from [0.0; 0.5]*WindSpeed.NormalOperation; as RMS [x; y] value. A second vector "Tracking.Accuracy.Track2D_hiWind" can be given as separate parameter for wind speeds in the range from [0.5; 1.0]*WindSpeed.NormalOperation (optional). The [min;max] intervals both of the elevation and the azimuth axis MUST be given for the test day in parameter Tracking.Accuracy.TrackingTestConditions.	Recommended measurement setup: The target and heliostat are aligned north-south, with a maximum deviation of +-10deg to north/south. The target normal vector should be parallel to north-south, a maximum deviation of +-10deg to north/south is permitted. Otherwise, observed tracking deviations have to be corrected for and the corrections have to be reported. In case the camera is placed off-axis (is normally the case), the target and/or the target is non-planar, an ortho-image has to be created. Be careful that in case of a non-planar target, (e.g. round tower surface), the correct length for ortho-image creation is used. To the current knowledge, for a cylindrical target (tower surface), this is the projected, not unwinded cylinder diameter. The tracking accuracy is determined by focusing the heliostat on a white target and continuous position measurement of the beam center during the course of a day for sun elevations over 10 degrees with a sampling rate of 1 per minute or higher. The images are evaluated regarding state-of-the-art methods like background correction etc. The beam center is determined by linear intensity	IQual

							weighting. The measured positions of the beam center of each measurement point *i* yield a distribution around the aim point. For each image, an instant tracking deviation in *x*-direction and in *y*-direction ($Track_{x,TCS,i}$ and $Track_{y,TCS,i}$) in mrad using the respective distances and applying angular relations (atan) is calculated. Don't forget to apply the factor 0.5 due to the reflection to get to the tracking accuracy. The coordinates in the target coordinate system (TCS) are transformed to the heliostat coordinate system (HCS). The time series of the instant 2D tracking deviation is calculated for each image *i* by $Track_{2D,TCS,i}$ = sqrt($Track_{x,TCS,i}^2$+$Track_{y,TCS,i}^2$). From the time series, the statistical values $Track_{2D,RMS}$ and Rayleigh parameter $Track_{2D,sR}$ can be derived. The 10-m wind speed close to the heliostat has to be measured to only use the data in the lower wind speed range [0; 0.5]*WindSpeed.NormalOperation. Comment: Although not being recommended, instead of using the linear intensity weighted beam center, the intensity peak of the beam could be used. It has to be documented which method has been used. Whileas using the linear intensity weighted beam center is more tolerant regarding poorly canted heliostats having various foci and gives an indication where most of the energy is focused, using the beam peak represents more the heliostat tracking mechanism (lower influence of aberation) and gives information about where the maximum flux is. Note: $Track_{2D,sR}$=1/sqrt(2)*$Track_{2D,RMS}$. The parameter RMS can be approximated by the *x*- and *y*-component of the tracking deviation (Tracking.Accuracy.Track_x and Tracking.Accuracy.Track_y): $Track_{2D,RMS}$ = ($Track_{x,RMS}^2$ + $Track_{y,RMS}^2$)$^{0.5}$. However, it is more precise to combine the individual deviations in *x*- and *y*-direction to the *2D* deviations and then apply the statistics.	
52	Tracking.Accuracy.Track_x_HCS $Track_{x,HCS}$	RMS: 0.75 MEAN: 0.01 STD: 0.75	mrad	string	<2 mrad	RMS, MEAN and STD of *x*-component (in heliostat coordinate system HCS) of tracking accuracy. Determination see Tracking.Accuracy.Track_2D_HCS. Note: The tracking accuracy is given as x- and y-component ($Track_{x,HCS}$ and $Track_{y,HCS}$) indicating performance on the target/receiver. However, the drive/axes characteristics of the heliostat are better characterized by the tracking accuracy around the two axes (heliostat axis system AS), using Tracking.Accuracy.Track_ax,AS1 ($Track_{ax1,AS}$) and Tracking.Accuracy.Track_ax2,AS ($Track_{,ax1,AS}$).	See Tracking.Accuracy.Track_2D_HCS	IQual
53	Tracking.Accuracy.Track_y_HCS $Track_{y,HCS}$	RMS: 0.75 MEAN: 0.00 STD: 0.75	mrad	string	<2 mrad	See Tracking.Accuracy.Track_x_HCS, replacing *x* by *y*.	See Tracking.Accuracy.Track_2D_HCS	IQual
54	Tracking.Accuracy. Tracking_HCS-TimeCorrelation $r_{Track}(Track_{x,HCS}, t)$, $r_{Track}(Track_{y,HCS}, t)$	[0.1; -0.2]	-	single vector	-1 to 1	Tracking Time Correlation ([*x*-time *y*-time]) or sample Pearson correlation coefficient between tracking behaviour and time. Determination see Tracking.Accuracy.Track_2D_HCS. Note: This parameter is given as two values in the heliostat coordinate system (HCS), indicating performance on the target/receiver. However, the drive/axes characteristics of the heliostat are better characterized by the correlation around the first and second axis (heliostat axis system AS), using Tracking.Accuracy.Tracking_AS-TimeCorrelation.	See procedure in Tracking.Accuracy.Track_2D_HCS for data acquisition. The time series of the tracking offsets $dx_{TCS,i}$ and $dy_{TCS,i}$ (or the tracking deviation $Track_{x,HCS,i}$ and $Track_{y,HCS,i}$) are correlated over time *t*. No special treatment of time input vector or tracking offset input vector is necessary while using the Pearson linear correlation coefficient. With x:=$Track_{x,HCS}$; x_i:=$Track_{x,HCS,i}$; x_{MEAN} = $Track_{x,HCS,MEAN}$, we calculate: $r_{Track}(x,t) = cov(x,t) / (\sigma_x*\sigma_t)$, or: $r_{Track}(x,t)$ =sum((x_i-x_{MEAN})*(t_i-t_{MEAN})) / (sqrt(sum(x_i-x_{MEAN})^2) * sqrt(sum(t_i-t_{MEAN})^2)) The same formulas apply for the *y*-direction, replacing *x* by *y*.	IQual
55	Tracking.Accuracy. Tracking_HCS-XYCorrelation $r_{track}(Track_{x,HCS}, Track_{y,HCS})$	0.2	-	single	-1 to 1	Correlation between the tracking behaviour in *x*- and *y*-direction. Determination see Tracking.Accuracy.Track_2D_HCS.	See procedure in Tracking.Accuracy.Track_2D_HCS for data acquisition. The time series of the tracking offsets $dx_{TCS,i}$ and $dy_{TCS,i}$ (or the tracking deviation $Track_{x,HCS,i}$ and $Track_{y,HCS,i}$) of the two	IQual

						Note: This parameter is given in the heliostat coordinate system (HCS), indicating performance on the target/receiver. However, the drive/axes characteristics of the heliostat are better characterized by the correlation around the first and second axis (heliostat axis system AS), using Tracking.Accuracy.Tracking_AS-Ax1Ax2Correlation.	directions are correlated with each other. No special treatment of time input vector or tracking offset input vector is necessary while using the Pearson linear correlation coefficient: With $x:=Track_{x,HCS}$; $xi:=Track_{x,HCS,i}$; $x_{MEAN} = Track_{x,HCS,MEAN}$, and $y:=Track_{y,HCS}$; $yi:=Track_{y,HCS,i}$; $y_{MEAN} = Track_{y,HCS,MEAN}$, we calculate: $r_{Track}(x,y) = cov(x,y) / (\sigma_x*\sigma_y)$, or: $r_{Track}(x,y) = sum((x_i-x_{MEAN})*(y_i-y_{MEAN})) / (sqrt(sum(x_i-x_{MEAN})^{2}) * sqrt(sum(y_i-y_{MEAN})^{2}))$	
56	Tracking.Safety.EmergDefocusTime	[1.3; 20] @ 21°C	s	single vector	0 to 600	Time span of heliostat defocus process, triggered by an emergency defocus event: First value: Time necessary between an alarm notification and the response of the heliostat; Second value: Total time span (incl. reaction time=first value) until the concentrator was redirected by 10 degrees from the aim point or by another defocus mechanism by e.g. releasing pressure of stretched membrane heliostats. Give maximum values of five measurements.	Electronic time clock; Start of time measurement when control defocus statement is launched in control room. Read time when heliostat reacts (=first value). Stop time when heliostat has been redirected 10 degrees from initial aimpoint position (=second value). Camera-Target method to measure movement of focus, or alternatively, inclinometer or protractor. The setup of the communication system has to be described in detail (e.g., where the control statement is given). Report the maximum value of 5 measurements.	IQual/Man
57	Tracking.Safety.StowPosition	face down, el=-10°	- /°	string	-	Description of the stow position of the heliostat, in which it remains at shutdown [face down / face up / vertical / etc.], giving additionally a numeric value for the inclination of the mirror surface relative to the horizontal (elevation=0 deg horizontal; negative elevation face down)	Inclinometer, protractor	IQual/Man
						HELIOSTAT CONTROL		
58	Control.Instrumentation. Communication	wired, RS485	-	string	-	System (wired / wireless / ...) and protocol (Modbus / ZigBee / etc.) used for communication between the central heliostat control system and the field heliostat	specified by manufacturer	Man
59	Control.Instrumentation. ControlReactionTime	spec: [0.11; 0.15]; measured: MEAN: 0.10 MAX: 0.13 STD: 0.02	ms	string	0.01 to 2	Specified mean and maximum reaction time [mean; maximum]. Measured reaction time of heliostat controller. Time from command input until movement of heliostat begins. Must be measured and qualified by measuring electrical signals (and not by manual stop watch or similar to avoid measurement errors).	Measurement by oscilloscope. Accuracy must be higher than 0.5%. The measurement has to be repeated at least 3 times. The mean and maximum values have to be given. The standard deviation has to be given, if there are high deviations between the individual measurements and the measurement is repeated more than 3 times. Test conditions: worst conditions, i.e. maximum moments by gravitation and (applied) wind force. The test conditions (temperature, loads) must be reported.	IQual/Man
60	Control.General.DriveSupplyType	electrical @230 V	-	string	-	Type of power supply to power the motion of the heliostat [electric @ voltage / hydraulic @ pressure / pneumatic @pressure / etc.]	specified by manufacturer	Man
61	Control.Power.InputVoltage	spec: [220; 230; 240]; measured: MEAN: 228.3 MAX: 230.2 STD: 1.6	V	string	1 to 999	Specified minimum, required and maximum input voltage [min; required; max] at heliostat connection point. Measured: Real mean and maximum value provided by the system to the local heliostat controller.	Manufacturer specification and measurement by volt meter. Accuracy must be higher than 0.5%. The measurement has to be repeated at least 3 times. The mean and maximum values have to be given. The standard deviation has to be given, if there are high deviations between the individual measurements and the measurement is repeated more than 3 times. Test conditions: Worst conditions, i.e. maximum moments by gravitation and (applied) wind force. The test conditions (temperature, loads) must be reported.	IQual/Man
62	Control.Power.InputPowerStandby	spec: 3.0W @21°C; meas: 2.9W @25°C	W	string	0.1 to 9999	Specified and measured mean input standby power of heliostat. The ambient temperature approximating the electronics temperature at the morning must be given.	Manufacturer specification and measurement by power meter. Accuracy must be higher than 0.5%. The measurement has to be repeated at least 3 times. The mean value has to be given. The standard deviation has to be given, if there are high deviations between the individual measurements and the measurement is repeated more than 3 times. Test conditions: Worst conditions, temperature must be given.	IQual/Man

63	Control.Power. InputPowerEmergDefocus	spec: [400; 450] @21°C; measured: MEAN: 397 MAX: 450 STD: 40 @25°C	W	string	1 to 9999	Specified input power [mean; maximum] during emergency defocus for the worst conditions, i.e. maximum moments by gravitation and (applied) wind force. Measured: MEAN, MAX and STD values of a least three measurements for the measured value. The ambient temperature approximating the drive temperature during the test must be given.	Measurement by power meter. Accuracy must be higher than 0.5%. The measurement has to be repeated at least 3 times. The mean and maximum values have to be given. The standard deviation has to be given, if there are high deviations between the individual measurements and the measurement is repeated more than 3 times. Test conditions: Worst conditions, i.e. maximum moments by gravitation and (applied) wind force. The test conditions (temperature, loads) must be reported.	IQual/Man
64	Control.Power. InputPowerColdStart	spec: [190; 200] @20°C; measured: MEAN: 189 MAX: 200 STD: 7 @15°C	W	string	1 to 9999	Specified input power [mean; maximum] during a cold start of the system at the morning (or after total shutdown and sufficient waiting time for electronic discharge). Measured: MEAN, MAX and STD values of a least three measurements for the measured value. The ambient temperature approximating the electronics temperature at the morning must be given.	see Control.Power.InputPowerEmergDefocus	IQual/Man
						LIMITS & TOLERANCES		
65	LimitsTol.WindSpeed. NormalOperation	8	m/s	single	1 to 20	Maximum wind speed (@ 10m height; 3-s gusts) for normal and unrestricted operation, for which the manufacturer guarantees proper operation without exceeding the here given tolerances and without damage to the heliostat	specified by manufacturer respecting the actual technical codes and procedures (mostly windtunnel analyses with FEM, partly supported by CFD) and safety factors	Man
66	LimitsTol.WindSpeed. ReducedOperation	20	m/s	single	1 to 25	Maximum wind speed (@ 10m height; 3-s gusts) for restricted operation: the manufacturer guarantees operation without damage to the heliostat. Accuracies may be exceeded.	specified by manufacturer respecting the actual technical codes and procedures (mostly windtunnel analyses with FEM, partly supported by CFD) and safety factors	Man
67	LimitsTol.WindSpeed. GustSurvival	40	m/s	single	1 to 70	Maximum wind speed (@ 10m height; 3-s gusts) for which the manufacturer guarantees no occurring damages to the heliostat when the heliostat is in the corresponding stow position	specified by manufacturer respecting the actual technical codes and procedures (mostly windtunnel analyses with FEM, partly supported by CFD) and safety factors	Man
68	LimitsTol..OperatingTemp	[-20;50]	°C	single vector	-99 to 99	[minimum; maximum] temperature for which normal operation of the heliostat is specified by the manufacturer	specified by manufacturer respecting the actual technical codes and safety factors	Man
						ORIENTATIVE COSTS		
69	Cost..Total	1'900 (Morocco)	€	single, string	1 to 99999	Orientative price for the heliostat, as mounted on gravel soil. The price is to be given with foundation costs for a specific country (location has to be given in parenthesis), EXW and without VAT for an assumed delivered number of 1000 heliostats, installation cost not included	specified by manufacturer	Man
70	Cost..SpecificWithoutFoundation	80.0	€/m²	single	1 to 500	Orientative price per square meter effective concentrator area for the heliostat, without foundation. The price is to be given EXW and without VAT for an assumed delivered number of 1000 heliostats, installation cost not included	specified by manufacturer	Man

IQual: Independent qualification organization/company; Man = manufacturer

A.2 Additional Descriptive Parameters (class-2)

n	Parameter Name (Symbol)	Value Example	Unit	Variable Type	Typical Range	Definition	Technique for Derivation of Parameter	Provided by (Lab/Man)
						HELIOSTAT CONFIGURATION		
71	HelioConfig.CoordinateSys.PACS *PACS*	*see report*	-	string	-	Please describe the principal axis coordinate system in the measurement report. Special coordinate system which is defined by the principle axes of the oscillations of the heliostat which can be caused by wind forces or other perturbations. Defining and reporting the PACS is only necessary if the wind-induced tracing deviation is reported in the PACS system. Remark: Wind-induced tracing deviation may be also given in the axes coordinate system (AS), or heliostat coordinate system (HCS). Details see section 3 "Symbols and General Definitions".	-	IQual
72	HelioConfig.General.Weight	355	kg	single	0 to 99999	Sum of the weight of all parts of the operative heliostat without foundation	specified by manufacturer	Man
73	HelioConfig.Foundation.Type	cube (gravel soil)	-	string	-	Foundation type [cube / cylinder / plate / earth anchor / etc.] and soil type	specified by manufacturer; as soil-dependant, several options can be listed, together with type of soil	Man
74	HelioConfig.Foundation.Material	concrete (gravel soil)	-	string	-	Foundation material [concrete / steel / etc.] and soil type	specified by manufacturer; as soil-dependant, several options can be listed, together with type of soil	Man
75	HelioConfig.Foundation. Dimensions	[1.5;1.5;1.0] (gravel soil)	m	single vector	0 to 10	Dimension (length, width, height) or (diameter, height) of foundation and soil type;	specified by manufacturer; as soil-dependant, several options can be listed, together with type of soil	Man
76	HelioConfig.Foundation.Depth	0.1 (gravel soil)	m	single	0 to 10	Depth of upper foundation surface over ground	specified by manufacturer; as soil-dependant, several options can be listed, together with type of soil	Man
77	HelioConfig.Foundation.Weight	400 (gravel soil)	kg	single	0 to 999	Foundation weight	specified by manufacturer; as soil-dependant, several options can be listed, together with type of soil	Man
78	HelioConfig.Foundation. NumberPerHeliostat	1 (gravel soil)	-	integer	0 to 10	Number of foundations per heliostat	specified by manufacturer; as soil-dependant, several options can be listed, together with type of soil	Man
79	HelioConfig.Pedestal.Type	pipe	-	string	-	Pedestal type [pipe / rectangular pole / frame / etc.]	specified by manufacturer	Man
80	HelioConfig.Pedestal.Material	steel	-	string	-	Pedestal material [steel / aluminum / etc.]	specified by manufacturer	Man
81	HelioConfig.Pedestal.Height	2.000	m	single	0 to 99	Pedestal height	specified by manufacturer	Man
82	HelioConfig.Pedestal. LateralExtension	0.4	m	single	0 to 20	Maximal extension / diameter	specified by manufacturer	Man
83	HelioConfig.Pedestal.Weight	80	kg	single	0 to 9999	Pedestal weight without control box	specified by manufacturer	Man
84	HelioConfig.Pedestal. FoundationFixType	screws	-	string	-	Manner of fixing on the foundation [screws / cast-in in foundation / etc.]	specified by manufacturer	Man
85	HelioConfig.Pedestal. ConcentratorMountType	[altitude-azimuth; screws]	-	string	-	Way of mounting concentrator to pedestal [altitude-azimuth / equatorial mounting / etc. ; fixing system]	specified by manufacturer	Man
86	HelioConfig.Conc.TotalArea	40.5	m^2	single	0 to 100	Total aperture area of concentrator (incl. gaps between mirror panels)	specified by manufacturer; controlled by lab by (laser) distance meter, tape measure, etc.	IQual/Man
87	HelioConfig.Conc.Weight	250	kg	single	0 to 9999	Weight of concentrator	specified by manufacturer	Man
88	HelioConfig.Support.Type	point-symmetric steel frame	-	string	-	General design type of the concentrator support [torque tube with roof-truss type / point-symmetric steel frame / metal tube ring / plastic enclosed / venetian blinds / etc.]	specified by manufacturer	Man

89	HelioConfig.Support.Material	steel	-	string	-	Main materials of the concentrator support [Steel / aluminum / carbon fiber / alloy / etc.]	specified by manufacturer	Man
90	HelioConfig.Support.Dimension	[3.5; 8]	m	single vector	0 to 20	Max. dimension parallel to [axis1; axis2] of rotation	specified by manufacturer	Man
91	HelioConfig.Support. NumberMirrorSupports	[8; 8]	-	single vector	0 to 20	Number of mirror supporting points parallel to [axis1; axis2]	specified by manufacturer	Man
92	HelioConfig.Support. FixingOfPanelsToSupport	3-points; screwed	-	string	-	Manner of fixing of mirror panels to support structure [3-point mount / 4-point mount / glued / screwed / etc.]	specified by manufacturer	Man
93	HelioConfig.Support.Weight	120	kg	single	0 to 9999	Support structure weight (without mirrors and tracking system)	specified by manufacturer	Man
94	HelioConfig.Panel.ReflectiveArea	4	m²	single	0 to 250	Total reflective area per mirror panel	specified by manufacturer; controlled by lab by (laser) distance meter, tape measure, etc.	IQual/Man
						CONCENTRATOR OPTICS		
95	Optics.Conc.CantingMethod	in field, on axis	-	string	-	Canting method [in field on axis / in field off axis / in workshop / on jig etc.]	specified by manufacturer	Man
96	Optics.Conc. DefWind_deltaSDmat *30x $\Delta SD_{x,mat}^{wind}$, 30x $\Delta SD_{y,mat}^{wind}$, or (30x $\Delta SD_{tan,mat}^{wind}$, 30x $\Delta SD_{rad,mat}^{wind}$)* + vector helio el., vector wind attack angle, wind speed	(5x3x2)-times [m;n] slope matrix, both in *x*-and *y*-dir., helio_el=[0 30 45 60 90]°, wind_attack= [0 30 60]°, wind=4m/s	mrad	matrices, single vectors, single	<20 mrad	Heliostat deformation due to wind loads: (5x3x2)=30 matrices containing change in slope deviations in mrad in horizontal (vertical) direction *x* (*y*) with respect to the case without wind for 5 heliostat elevations, 3 azimuth wind attack angles relative to the concentrator surface and 2 wind speeds (0.5, 1.0)*WindSpeed.NormalOperation: in the most critical condition (1. row for static loads). 10-m wind speed must be measured close to the heliostat. Accepted alternative: Only 1 simulation for average azimuth, average elevation, specific wind direction (must be documented) and 0.5*WindSpeed.NormalOperation. The 3 [m;n] matrices give the underlying	As in reality the boundary conditions are almost impossible to reach, preferably wind tunnel experiments and FEM simulations may provide the results. When using CFD, there is the disadvantage of uncertainty of modeling errors. Please see Optics.Conc.DefGravity_deltaSDmat for further comments about resolution, data processing, reporting, etc. // Dynamic deformation caused by wind could be measured by stereo photogrammetry or dynamic deflectometry.	IQual
97	Optics.Focus.PanelFocalLength		m	integer matrix	0 to 9999 or NaN (flat)	Measured mirror panel focal lengths, given for each mirror panel (NaN for plane mirror panel). Use the vector or matrix format, defined in parameter HelioConfig.Panel.Number: mat[n_x n_y] (rectangular conc. outline) or vec [*n*] (rotationally symmetric conc. outline) or mat [n_i n_o] (rotationally symmetric conc. outline with inner (*i*) and outer ring (*o*)) or similar	The mirror panel focal length $f_{mirror\ panel}$ can be estimated with the measured heliostat slope data (given by parameters Optics.Conc.SD$_{x/y}$): A sphere or paraboloid as defined in Optics.Panel.CurvatureMounted is fitted to the measured mirror panel shape by minimizing the normal vector deviations between the nominal shape and measured shape using a ROBUST least square method or similar: For spherical panel shape: $f_{mirror\ panel}=R/2$, with the radius *R* of the spherical panel curvature. For parabolic panel shape: $f_{mirror\ panel}=1/(4af)$, with *af* being the coefficient of the quadratic term of the parabolic curve description of the mirror panel. A value of "infinity" classifies a flat non-curved panel. Alternatively, using an on-axis configuration (sun-mirror panel-target on one axis), the sun can be reflected to a white target while the distance between target and mirror panel is increased. The focal length of the mirror panel is reached, where the smallest focal spot is observed, i.e. where the 95%-radius is smallest. The same experiment can be done virtually using a raytracing software. The chosen method has to be reported.	IQual
98	Optics.Focus.ConcFocalLength f_{conc}	[100]	m	single	0 to 9999 or NaN (flat)	Measured concentrator focal length.	The concentrator focal length f_{conc} can be estimated with the measured heliostat slope data (given by parameters Optics.Conc.SD$_{x/y}$): A sphere or paraboloid as defined in Optics.Conc.NominalShape is fitted to the measured concentrator shape by minimizing the normal vector deviations between the nominal shape and measured shape using a ROBUST least square method or similar: For spherical concentrator shape: $f_{conc}=R/2$,	IQual

							with the radius *R* of the spherical concentrator curvature. For parabolic shape *fconc*=1/(4*af*), with af being the coefficient of the quadratic term of the parabolic curve description of the concentrator. A value of "infinity" classifies a flat non-curved concentrator. In case of a special heliostat shape defined in Optics.Conc.NominalShape, one should use the formula parabolic shape f_{conc}=1/(4*af*).	
						TRACKING		
99	Tracking.Axes.Drive	[rim drive; el. motor w. planetocentric gear drive]	-	string	-	Drive type for [first; second] tracking axis; [electric motor with planetocentric gear drive / electric motor with jackscrew / pipe-in-pipe / center drive / rim drive /etc.]	specified by manufacturer	Man
100	Tracking.Axes.Speed	[50; 100]	°/min	single vector	0 to 999	Maximum shaft speed range or slew rate which determines the velocity of angular rotation of [first; second] axis	specified by manufacturer	Man
101	Tracking.Axes.MaxPower	[500; 300]	W	single vector	0 to 9999	Maximum value of power input of the drive of [first; second] tracking axis	specified by manufacturer	Man
102	Tracking.Axes.PowerAxisAtRest	[20; 10]	W	single vector	0 to 999	Power consumption of the drive of [first; second] tracking axis when at rest	specified by manufacturer	Man
103	Tracking.Accuracy. WindConditionsAndSetup	[u_{10m}=8m/s; el=30°; attack=0°; z_0=0.05m; ρ_{Air}=1.293 kg/m3]	-	string	-	Vector defining the wind conditions and geometric setup for which the wind induced tracking error Tracking.Accuracy.$Track_{x/y,CCS}^{wind}$ is valid. The vector contains 5 entries: [10-minute mean wind speed at 10 meter height above ground, heliostat elevation angle, wind angle of attack, terrain roughness length, air density]. The values [$u_{10}m$=8m/s; el=30°; attack=0°; z_0=0.05m; rho_{Air}=1.293 kg/m3] should be used for comparability reasons.	This is a definition.	
104	Tracking.Accuracy. Track_x_CCS_wind $\Delta Track_{x,CCS,wind}$	MEAN: 0.3 STD: 0.2	mrad		<1 mrad	MEAN and STD of the wind-induced tracking deviation (*x*-component), defined in the concentrator coordinate system (CCS) for direct comparability between heliostats under the geometric and wind conditions defined in Tracking.Accuracy. WindConditionsAndSetup. Definition in axes system (AS) is also possible. It only appears under wind load and is an additional error which adds up to the general tracking error (Tracking.Accuracy.Track). Wind-induced tracking error consists of a static component (MEAN) and a dynamic component (STD). Both are related to a 10-minute period at full-scale. The dynamic component (STD) can be further divided into a background and a resonant component. The background component accounts for inevitable oscillations of the heliostat, mainly made up of a quasi-static "sway" of the heliostat. The resonant component accounts for additional oscillations due to the excitation of eigenfrequencies and is superimposed to the background component. With a good design, the resonant component can be considered negligible and the dynamic background component describes the STD sufficiently well. Tests on how to estimate the impact of the resonant component for a certain heliostat will be provided in the future.	The wind-induced tracking deviation is calculated through a customized procedure (wind acceptance test), see [Blume 2023a] for details. The procedure is based on an analytical model that describes the wind-induced tracking deviation based on only few input parameters: 1. The parameter Tracking.Accuracy. WindConditionsAndSetup defines: u10m; heliostat elevation; wind attack angle; z0; ρAir. 2. Heliostat geometry (elevation axis height, conc. characteristic length and surface area). 3. Mechanical parameters (concentrator stiffness, eigenfrequencies*, damping ratios*). The mechanical parameters can be derived through a simple procedure at the real-scale heliostat, termed pulling test. During the pulling test, the heliostat must be deflected to a small degree, e.g. through a lashing strap. The conc. deviation in mrad can measured by an inclinometer or a simple laser-measurement system: laserpointer on white canvas, the applied turning moment by a force or torque meter. The ratio of both delivers the concentrator stiffness, more precisely the inverse concentrator stiffness (mrad/Nm). If the eigenfrequencies and damping ratios are to be determined as well, a second part of the test must be conducted: After the concentrator has been deviated to a certain extent, the lashing strap (or another device) must be released so that the concentrator oscillates freely. By recording this oscillation, the eigenfrequencies and damping ratios can be derived. All input parameters are then applied to the analytical model and the desired wind-induced tracking deviation can be calculated. Note 1: At the current stage of development, the user is required to provide the non-dimensional aerodynamic moment coefficients (related to x_{CCS} and y_{CCS}) to the model. Sets of moment coefficients	IQual

						are available in pertinent literature. In a later development, these coefficients shall be prescribed by the acceptance test. If dedicated wind tunnel studies were conducted for the heliostat, moment coefficients may also be extracted from such study. Another set of coefficients (strictly speaking only for pentagonal heliost.) is given in Blume et al. (2023b): Full-scale investigation, https://doi.org/10.1016/j.solener.2022.12.016 Note 2: For detailed equations on the analytical model, see Blume et al. (2023a), Simplified analytical model, https://doi.org/10.1016/j.solener.2023.03.055 * The eigenfrequencies and the damping ratios have to be provided ONLY if the dynamic resonant response is to be calculated. With a good design, the dynamic response is negligible.	
105	Tracking.Accuracy. Track_y_CCS_wind $\Delta Track_{y,CCS,wind}$	MEAN: 0.3 STD: 0.2	mrad		<1 mrad	See Tracking.Accuracy.Track_x_CCS_wind, replacing *x* by *y*.	see Tracking.Accuracy.Track_x_CCS_wind	IQual
106	Tracking.Accuracy. Track_x_CCS_backlash $\Delta Track_{x,CCS,backlash}$	[-0.3; +0.4]	mrad		<2 mrad	Range of the backlash-induced tracking deviation (*x*-component) around a certain zero position, defined in the concentrator coordinate system (CCS) for direct comparability between heliostats. Definition in axes system (AS) is also possible. Due to backlash in the drives, the concentrator can be deviated to a certain extend at almost zero load. The range (in mrad) up to which the concentrator is able to rotate under almost zero load describes the backlash-induced tracking deviation. Note: The backlash-induced tracking deviation must not counted twice which could happen because the backlash occurs and evolves in particular if wind is present as wind can induce the necessary amount of load to set the concentrator in motion. So, the general tracking accuracy (Tracking.Accuracy.Track) can already include the backlash-induced tracking deviation, e.g. if the general tracking accuracy was measured through the target method and wind was present. Therefore, the parameter Tracking.Accuracy.Backlash-Induced.Track may only added to the general tracking accuracy if almost no wind was present during the measurement of the general tracking accuracy.	One possible procedure to measure the backlash-induced tracking deviation is the following. First, install a measurement device which allows to measure the movement/deviation of the concentrator (e.g. an inclinometer or a laser-measurement system, for further information on the laser-measurement system see also the explanation on Tracking.Accuracy.Track_x_HCS_wind). Second, carefully/slowly pull the concentrator to one side e.g. by using a lashing strap. This is the reference position. Start the recording of the concentrator movement/deviation. Third, carefully/slowly pull the concentrator to the opposite side from the reference side/position. Leave the concentrator untouched and read the movement/deviation.	IQual
107	Tracking.Accuracy. Track_y_CCS_backlash $\Delta Track_{y,CCS,backlash}$	[-0.3;+ 0.3]	mrad		< 2 mrad	See Tracking.Accuracy.Track_x_CCS_backlash, replacing *x* by *y*.	See Tracking.Accuracy.Track_x_HCS_backlash, replacing *x* by *y*	IQual
108	Tracking.Accuracy.Track_ax1_AS $Track_{ax1,AS}$	RMS: 0.75 MEAN: 0.01 STD: 0.75	mrad	string	<2 mrad	RMS, MEAN and STD of ax1-component (in heliostat axis system AS) of tracking accuracy.	Detemination see Tracking.Accuracy.Track_2D_HCS. The tracking accuracy $Track_{ax1,AS}$ is evaluated by transforming the observed tracking deviation on the target coordinate system (TCS), e.g. via the HCS, to the tracking axis 1 of the heliostat axis system (AS).	IQual
109	Tracking.Accuracy.Track_ax2_AS $Track_{ax2,AS}$	RMS: 0.75 MEAN: 0.00 STD: 0.75	mrad	string	<2 mrad	See Tracking.Accuracy.Track_ax1_AS, replacing *ax1* by *ax2*	See Tracking.Accuracy.Track_ax1, replacing *ax1* with *ax2*	IQual
110	Tracking.Accuracy. Tracking_AS-TimeCorrelation *rTrack(Trackax1,t),* *rTrack(Trackax2,t)*	[0.1; -0.2]	-	single vector	-1 to 1	Tracking Time Correlation ([*ax1*-time, *ax2*-time]), or sample Pearson correlation coefficient between tracking behaviour of ax1 and time (ax2 and time) in the heliostat axis system AS. It describes the drive/axes characteristics of the heliostat (in contrast to Tracking.Accuracy.Tracking_HCS-TimeCorrelation which describes the performance on a target). Determination see Tracking.Accuracy.Track_2D_HCS. Note: The measured values of the observed tracking deviation in the target coordinate system (TCS) must be processed, e.g. via the HCS, to the tracking axis 1 and axis 2 of the heliostat axis system (AS). If the TCS *x*- and *y*-axes do not coincide with the direction of first and second tracking axes *ax1* and *ax2*, this parameter differs from parameter Tracking.Accuracy.Tracking_HCS-TimeCorrelation.	See procedure in Tracking.Accuracy.Track_2D_HCS for data acquisition. The time series of the tracking deviation $Track_{ax1,AS,i}$ ($Track_{ax2,AS,i}$) given in the heliostat axis system AS, is correlated over time *t*. No special treatment of time input vector or tracking offset input vector is necessary while using the Pearson linear correlation coefficient. With $ax1 := Track_{ax1,AS}$; $ax1_i$: $=Track_{ax1,AS,i}$; $ax1_{MEAN}$:= $Track_{ax1,AS,MEAN}$, we calculate: $r_{Track}(ax1,t)$ = cov($ax1,t$) / (σ_{ax1}*σ_t), or: $r_{Track}(ax1,t)$ =sum(($ax1_i$ -$ax1_{MEAN}$)*(t_i-t_{MEAN})) / (sqrt(sum($ax1_i$ - $ax1_{MEAN}$)^2) * sqrt(sum(t_i-t_{MEAN})^2))	IQual

							The same formulas apply for the *ax2*-direction, replacing *ax1* by *ax2*.	
111	Tracking.Accuracy. Tracking_AS-Ax1Ax2Correlation $r_{track}(Track_{ax1}, Track_{ax2})$	0.2	-	single	-1 to 1	Sample Pearson correlation between the tracking behaviour around axis1 and axis2 in the heliostat axis system AS. It describes the drive/axes characteristics of the heliostat (in contrast to Tracking.Accuracy.Tracking_HCS-XYCorrelation which describes the performance on a target). Determination see Tracking.Accuracy. Track_2D_HCS. Note: The measured values of the observed tracking deviation in the target coordinate system (TCS) must be processed, e.g. via the HCS, to the tracking axis 1 and axis 2 of the heliostat axis system (AS). If the TCS x- and y-axes do not coincide with the direction of first and second tracking axes *ax1* and *ax2*, this parameter differs from parameterTracking.Accuracy.Tracking_HCS-XYCorrelation.	See procedure in Tracking.Accuracy.Track_2D_HCS for data acquisition. The time series of the tracking deviation around axis 1 ($Track_{ax1,AS,i}$) and axis 2 ($Track_{ax2,AS,i}$) are correlated. With $ax1 := Track_{ax1,AS}$; $ax1_i := Track_{ax1,AS,i}$; $ax1_{MEAN} := Track_{ax1,AS,MEAN}$, and $ax2 := Track_{ax2,AS}$; $ax2_i := Track_{ax2,AS,i}$; $ax2_{MEAN} := Track_{ax2,AS,MEAN}$, we calculate: $r_{Track}(ax1,ax2) = cov(ax1,ax2) / (\sigma_{ax1} * \sigma_{ax2})$, or: $r_{Track}(ax1,ax2) = sum((ax1_i - ax1_{MEAN})*(ax2_i - ax2_{MEAN})) / (sqrt(sum(ax1_i - ax1_{MEAN})^2) * sqrt(sum(ax2_i - ax2_{MEAN})^2))$	IQual
112	Tracking.Accuracy.CanonicalMoveTimeIntervalAx1Ax2 *dt*	MEAN: [1.5; 1.5] STD: [0.1;0.2]	s	string	0 to 60	Time interval between actuations of [first;second] rotation axis. Determined by a continuous high-speed position measurement of the beam center. The mean value and standard deviation must be given for both the axis1 and axis2. Note: This parameter describes the target tracking behaviour of the heliostat investigated. The canonical movement time interval is influenced by various factors, e.g. the programmed triggering by the control system, the communication speed to the heliostats, or any time interval caused inside the heliostat control boxes.	Measurement of the time interval between actuations of [first;second] rotation axis. Determination by a continuous high-speed position measurement of the beam center (at least 10 frames/sec) during several minutes for low wind speeds in the range from maximal (0.0; 0.5)*WindSpeed.NormalOperation. For data processing information, see the procedure in Tracking.Accuracy.Track_ax1/ax2. The mean value and standard deviation must be given for both the axis 1 and axis2.	IQual
113	Tracking.Accuracy.Controlled	no	-	string	-	Brief statement on an eventual control mechanism of the tracking position [yes/no]	specified by manufacturer	Man
114	Tracking.Safety.StartupTime	0.5	min	single	0 to 99	Time for start-up of the heliostat to reach a standard start-up position (defined to azimuth angle 60°, elevation angle 30°) from the stow position (defined in Tracking.Safety.StowPosition).	Electronic time clock; Start of time measurement when control startup statement is launched in control room. Stop when heliostat has reached the desired position.	IQual/Man
115	Tracking.Safety. EmergDefocusType	active axis movement	-	string	-	Procedure taken for beam defocus of the heliostat [active movement of tracking axes / fail-safe gravity driven movement / defocus by vacuum loss of stretched membrane heliostat etc.]	specified by manufacturer	Man
116	Tracking.Safety.SafeMode	shutdown to stow position by battery	-	string	-	Brief description on the procedure and taken measures in the case of power loss or interrupted control communication to the heliostat	specified by manufacturer	Man
						CONTROL		
117	Control.Instrumentation. SystemType	microprocessor controlled	-	string	-	Brief description of the general system type used to control the heliostat [microprocessor controlled, calculation of sun vector / measurement of sun vector / combination calculation+measurement / video camera control / etc.]	specified by manufacturer	Man
118	Control.Instrumentation. DataAcquisitionSystem	I/O bus system 4-20mA	-	string	-	Brief description of the system used for data acquisition within the communication of the heliostat control system and the heliostat drives [I/O bus system 4-20mA / WiFi / None / etc.]	specified by manufacturer	Man
119	Control.Instrumentation. ElectronicInterface	PLC	-	string	-	Type, name and brief description of the used electronic interface	specified by manufacturer	Man
120	Control.Instrumentation. SoftwareInterface	Labview	-	string	-	Type, name and brief description of the used software interface	specified by manufacturer	Man
121	Control.Instrumentation. RotationAxis	[position encoders; position encoders]	-	string	-	Instrumentation used for steering of [first; second] rotation axis [end limit switches, position encoders, displacement sensors, etc.]	specified by manufacturer	Man
122	Control.Power. OverloadProtection	no	-	string	-	Brief description if (yes / no) and which type of overload protection is existent	specified by manufacturer	Man

					LIMITS			
123	LimitsTol.Foundation. MaxInclination	1	mrad	single	0 to 99	Maximal allowed deviation of the inclination of the leveling of the heliostat foundation	specified by manufacturer	Man
124	LimitsTol.Pedestal.MaxInclination	[1; 1]	mrad	single vector	0 to 99	Maximal allowed deviation of the inclination of the heliostat pedestal in reference to [first; second] tracking axis	specified by manufacturer	Man
125	LimitsTol.ConcSuppStruct. MaxInclination	[1; 1]	mrad	single vector	0 to 99	Maximal allowed deviation of the inclination of the mounting of the support structure of the concentrator in reference to [first; second] tracking axis	specified by manufacturer	Man
126	LimitsTol.MaxTracking. TrackMaxRMS_ax1_ax2	[RMS 1.2; RMS 1.2]	mrad	single vector	0 to 99	Maximum allowable limit of the RMS deviation of the true beam direction to the aim point in reference to [first; second] tracking axis for maximum wind speed value with normal operation.	Currently, if specified, the manufacturer provides this value as upper guarantee value. This value can be measured by doing the tests described in Tracking.Accuracy.Track_x/y_CCS_wind.	Man
127	LimitsTol.MaxBeamDeflection. DueToWindNormalOp	1.8	mrad	single	0 to 99	Maximal beam deflection due to wind loads for the maximum wind speed value with normal operation	Currently, if specified, the manufacturer provides this value as upper guarantee value. This value can be measured by doing the tests described in Tracking.Accuracy.Track_x/y_CCS_wind.	Man
128	LimitsTol.MaxBeamDeflection. PersistentDueMaxWind	[1; 1]	mrad	single vector	0 to 99	Persistent beam deflection in reference to [first; second] tracking axis which might remain maximally after the heliostat was affected by wind loads with wind velocities up to the specified survival speed limit for wind	specified by manufacturer	Man
129	LimitsTol.MaxBeamDeflection. DueToGravity	[1; 1]	mrad	single vector	0 to 99	Maximum value allowed for the beam deflection due to gravitation loads resulting for [first; second] axis	specified by manufacturer	Man
130	LimitsTol.MaxBeamDeflection. DueToTemp	[1; 1]	mrad	single vector	0 to 99	Maximum value allowed for beam deflection due to temperature effects and/or variations, affecting [first; second] axis	specified by manufacturer	Man
131	LimitsTol.MaxConcTwist. DueToWindNormalOp	1	mrad	single	0 to 99	Maximal twist (around axis 1) of the concentrator at the limit wind speed of normal operation, usually for vertical heliostat orientation	Currently, if specified, the manufacturer provides this value as upper guarantee value. This value can be confirmed by doing the tests described in Tracking.Accuracy.Track_x/y_CCS_wind.	Man
132	LimitsTol.MaxConcTilt. DueToWindNormalOp	1	mrad	single	0 to 99	Maximal tilt (around axis 2) of the concentrator at the limit wind speed of normal operation, usually for vertical heliostat orientation	Currently, if specified, the manufacturer provides this value as upper guarantee value. This value can be confirmed by doing the tests described in Tracking.Accuracy.Track_x/y_CCS_wind.	Man
133	LimitsTol.Drive.Clearance	[1; 1]	mrad	single vector	0 to 99	Maximum angular value of the clearance of the drive of [first; second] tracking axis	specified by manufacturer	Man
134	LimitsTol.Drive. MaxTorqueNormalOp	[10; 5]	Nm	single vector	0 to 9999	Maximal occurring torsional moment of the drive of [first; second] tracking axis during normal operation with accurate tracking	specified by manufacturer	Man
135	LimitsTol.Drive. MaxTorqueMovetoStow	[30; 15]	Nm	single vector	0 to 9999	Maximal occurring torsional moment of the drive of [first; second] tracking axis when moving the heliostat to stow position	specified by manufacturer	Man
136	LimitsTol.Drive. MaxTorqueSurvivalWind	[80; 80]	Nm	single vector	0 to 9999	Maximally resisted torsional moment of the drive of [first; second] tracking axis for survival wind speeds in stow position	specified by manufacturer	Man
137	LimitsTol.Hailstone. SteelBallHeight	-	m	single	0.4 to 1.8	Maximum fall height of 150g-steel ball which the concentrator is specified to survive without damage according to EN 12975-2:2006, method 1 (if method 1 is used, then parameter LimitsTol.Hailstone.Velocity is not used)	Maximum fall height of 150g-steel ball which the concentrator is specified to survive without damage; 10x repetition, according to EN 12975-2:2006, (if method 1 is used, then LimitsTol.Hailstone.parameter Hailstone.Velocity is not used)	IQual
138	LimitsTol.Hailstone.Velocity	23	m/s	single	0 to 40	Maximum velocity of hailstones which the concentrator is specified to survive without damage (ice ball diameter 25mm) according to EN 12975-2:2006, method 2 (if method 2 is used, then parameter LimitsTol.Hailstone.SteelBallHeight is not used)	Maximum velocity of hailstones which the concentrator is specified to survive without damage (ice ball diameter 25mm); 10x repetition, according to EN 12975-2:2006, method 2 (if method 2 is used, then parameter LimitsTol.Hailstone.Hailstone. SteelBallHeight is not used)	IQual
139	LimitsTol.Hailstone.SnowLoad	0.65	kN/m 2	single	0 to 3	Maximum snow load in stow position to survive without damage.	specified by manufacturer	Man

140	LimitsTol.Temp.ColdWaterShock	yes: panel tested: x K/s	-	string	yes+info/no	Is heliostat tested regarding temperature shock conditions? [no, yes]. If yes, give component and tested shock boundary conditions/norm	specified by manufacturer	Man
141	LimitsTol.Lifetime. MirrorDegradation	0.25	%/a	single	0 to 9	Absolute value in percent points of a reduction of the reflectance value which may occur per year	Currently, if specified, the manufacturer provides this value as upper guarantee value. The reflectance of degraded mirrors can be measured according to the SolarPACES reflectance guideline.	Man/(IQual)
142	LimitsTol.Lifetime.Concentrator	15	years	string	1 to 99	Mean lifetime of the concentrator when the heliostat is operated at standard conditions, remaining within specified tolerances, including an average substitution rate of the reflective surface	specified by manufacturer	Man
143	LimitsTol.Lifetime. SupportStructure	20	years	string	1 to 99	Mean lifetime of the support structure when the heliostat is operated at standard conditions, remaining within specified tolerances	specified by manufacturer	Man
144	LimitsTol.Lifetime.Pedestal	20	years	string	1 to 99	Mean lifetime of the heliostat pedestal when the heliostat is operated at standard conditions, remaining within specified tolerances	specified by manufacturer	Man
145	LimitsTol.Lifetime.Mechanics	10	years	string	1 to 99	Mean lifetime of the mechanical components of the drives, joints and hinges when operated at standard conditions, remaining within specified tolerances and assuming average substitution rates	specified by manufacturer	Man
146	LimitsTol.Lifetime.Electronics	10	years	string	1 to 99	Mean lifetime of the electronic components when the heliostat is operated at standard conditions, remaining within specified tolerances and assuming average substitution rates	specified by manufacturer	Man
						COSTS		
147	Cost..InstallationTime	2	h	single		Average time which is necessary for the installation of one heliostat, excluding the foundation	specified by manufacturer	Man
148	Cost..SpecificOM	[1; 1.5]	€/m² a	single vector		Estimated average specific costs for operation and maintenance of the heliostat per square meter and year, repair works, spare parts etc. for ["normal"; "harsh"] conditions, without cleaning effort	specified by manufacturer	Man
						O&M		
149	O&M.Maintenance.List	hydraulic oil control: 1x/yr hydraulic oil replacem: 1x/5 yrs	-	string	-	Maintenance table containing each heliostat component (e.g. "elevation drive", "UPS battery"), the maintenance needed (e.g. "control", "replacement", "oil refilling") and the time interval needed (e.g. "each year", "each 5000h operating hours") between maintenance works. In a further column, the conditions for this numbers can be given (e.g. "normal" or "harsh", "temperatures below -30°C", etc). Several lines are permitted for the same component in case that that intervals between maintenance change with the conditions.	specified by manufacturer	Man
150	O&M.OpPowerConsum. CurvaturePowerConsumMean	0	W/m²	single	0 to 100	Canting power per total reflective aperture area in case power is necessary to maintain concentrator curvature. This power consumption is included in the class-1 Control.Power parameters.	Measurement by power meter. Accuracy must be higher than 1%. The measurement has to be done over a whole day from sunrise to sunset and the mean value has to be given.	IQual/Man
151	O&M.OpPowerConsum.Tracking	20	W	single	0 to 9999	Mean Power consumption of the heliostat for a standard operation at a sunny day: Tracking over 12 hours, including start-up and stowing of the heliostat	specified by manufacturer	Man
152	O&M.OpPowerConsum.StandBy	3	W	single	0 to 9999	Mean Power consumption of the heliostat in stand-by conditions (not tracking, e.g. stow)	specified by manufacturer	Man
153	O&M.Consumables.Others	oil 1l	kg/a or other	[string; single]	0 to 999	List of further consumables, given with the mean annual quantity needed for standard operation of the heliostat [type; amount]	specified by manufacturer	Man
154	O&M.Maintenance. IdealWashingPosition	vertical	-	string		Recommended washing position(s): vertical/face-up/face-down/elevation-angle= x°	specified by manufacturer	Man

IQual: Independent qualification organization/company; Man = manufacturer

A.3 Image on Target, Beam Parameters, Error Components, and Focus Deviation on Target (class-3)

n	Parameter Name (Symbol)	Value Example	Unit	Variable Type	Typical Range	Definition	Technique for Derivation of Parameter	Provided by (Lab/Man)
						IMAGE ON TARGET		
155	Optics.ImageOnTarget.Conditions	az=0°; el=30°; no wind; no temp. load; on axis; SL=100m; sunsh. Buie_CSR2%	-	string		Description of conditions under which the beam dispersion (i.e. all Optics. ImageOnTarget parameters) is determined (heliostat az./elevation; wind; temperature; sunshape; relative configuration of: target, heliostat, and sun). For simulations, use of an on-axis configuration of sun-heliostat-target, sunshape Buie_CSR2%, heliostat focal length=100m and distance heliostat - target=SL=100m, no wind, no temperature load, azimuth= 0° and elevation= 30° is recommended. For experiments, similar values to those of simulations are preferred, if possible.	This is a definition.	IQual
156	Optics.ImageOnTarget. ReflectedPower	19.5	kW	single	0 to 200	Total reflected power (within 90% intensity angle, at 1000 W/m² and for clean mirrors). Further conditions are reported under parameter: Optics.ImageOnTarget.Conditions	Raytracing simulations using slope deviation matrices and conditions being described under Optics.Beam. BeamQualityConditions. Simulations are the preferred option. Alternatively, by experimental beam characterization, i.e. by focusing the heliostat on a white target taking an image of the dispersed beam on the target. For experiments, similar conditions than those of simulations are preferred, if possible.	IQual
157	Optics.ImageOnTarget.FluxProfile *I(x,y)*	fluxfile.xls	kW/ m²	matrix or file	-	Measured or simulated spatial irradiance intensity distribution *I* on a target at 1000 W/m² and for clean mirrors. Further conditions are reported under parameter: Optics.ImageOnTarget.Conditions	See Optics.ImageOnTarget.ReflectedPower	IQual
158	Optics.ImageOnTarget. 90PercentAngle	4	mrad	single	0 to 99	Mean rotational angle deviation from center ray (half angle), in which 90% of the energy is reflected. Conditions are reported under parameter: Optics.ImageOnTarget.Conditions	See Optics.ImageOnTarget.ReflectedPower	IQual
159	Optics.ImageOnTarget. MeanConcentration90	5.5	-	single	0 to 999	Ratio of the mean flux density of the reflected irradiance within the 90%-angle to the natural non-concentrated direct solar beam irradiance for clean mirrors. Further conditions are reported under parameter: ConcOptics.ImageOnTarget.Conditions	See Optics.ImageOnTarget.ReflectedPower	IQual
160	Optics.ImageOnTarget. PeakPowerDensity	6	kW/ m²	single	0 to 999	Maximum value of the flux intensity distribution of the heliostat in the focal plane at perpendicular incidence angle for a solar irradiance value of 1000 W/m² and clean mirrors. Further conditions are reported under parameter: Optics.ImageOnTarget.Conditions	See Optics.ImageOnTarget.ReflectedPower	IQual
161	Optics.ImageOnTarget. TotalBeamDispersion $\sigma_{TotBeamDisp}$	circ: 4.60 *xy*:[3.6; 2.9] *uv*:[3.8; 2.6]	mrad	string	0 to 99	Superposition of all optical influences of the concentrator contributing to a dispersion of the solar beam on the target (excl. focus deviation), expressed as sigma of a circular normal ("circ") or elliptic normal (=bivariate) probability density function ("*xy*" = axes of TCS, "*uv*" = major axis of TCS), due to deviations of the true concentrator shape from the ideal shape for a defined heliostat azimuth/elevation angle + wind + temp. conditions, heliostat orientation and sunshape (given in Optics.ImageOnTarget.Conditions). Additional to the "circ"-sigma, two further vectors can be given describing the expansion of the beam in direction of two normal axes: Either writing as *x/y* components (horizontal and vertical target coordinate system TCS axis), or the *u/v* component (eigen-axis *u* and eigen-axis *v*).	See Optics.ImageOnTarget.ReflectedPower	IQual
162	Optics.ImageOnTarget. TotalHelioDispersion $\sigma_{TotHelioDisp}$	circ: 5.06 *xy*:[3.7; 3.5] *uv*:[3.6; 3.6]	mrad	string	0 to 99	Superposition of all optical influences of the concentrator contributing to a dispersion of the solar beam on the target (i.e. TotalBeamDispersion incl. focus deviation due to aimpointing), expressed as sigma of a circular normal ("circ") or elliptic normal (=bivariate) probability density function ("*xy*" = axes of TCS, "*uv*" = major axis of TCS). More details read also Optics.ImageOnTarget. TotalBeamDispersion.	The total heliostat dispersion being the convolution of total beam dispersion (Optics.ImageOnTarget.TotalBeamDispersion) and Focus Deviation (Tracking.FocusDeviationOnTarget.Focus2D) is derived approx. by the formula: $\sigma_{TotHelioDisp}$ = sqrt ($\sigma_{TotBeamDisp}^2$ + $Focus_{2D,RMS}^2$), if mean value of pointing error is zero.	IQual
						BEAM SHAPE OPTICS		

163	Optics.Beam. BeamQualityConditions	az=0°; el=30°; no wind; no temp. load	-	string		Description of conditions under which the beam quality is determined (heliostat az./elevation; wind; temperature)	n/a	IQual
164	Optics.Beam.BeamQuality σ_{BQ}	circ: 4.01 *xy*:[3.0; 2.7] *uv*:[3.2; 2.4]	mrad	string	0 to 99	2D beam dispersion on the target, expressed as sigma of a circular normal ("circ") or elliptic normal (=bivariate) probability density function ("xy" = axes of TCS, "uv" = major axis of TCS), due to deviations of the true concentrator shape from the ideal shape for a defined heliostat azimuth/elevation angle + wind + temp. conditions (given in Optics.Beam.BeamQualityConditions). Additionally to the "circ"-sigma, two further vectors can be given describing the expansion of the beam in direction of two normal axes: Either writing as x/y components (horizontal and vertical target coordinate system TCS axis), or the u/v component (eigen-axis u and eigen-axis v).	Raytracing using slope deviation matrices applying parallel rays and an on-axis configuration (sun-mirror panel-target on one axis) under conditions described under Optics.Beam.BeamQualityConditions. This is the recommended procedure. Alternatively, by experimental beam characterization, i.e. by focusing the heliostat on a white target and measuring the 2D 1-sigma angular standard deviation of the dispersed beam on the target. This value has to be corrected for sunshape and astigmatism effects which can be done iteratively by using a raytracer. However, this procedure is not recommended.	IQual
165	Optics.Beam.HelioQuality σ_{HQ}	circ: 4.59 *xy*:[3.1; 3.4] *uv*:[3.2; 3.3]	mrad	string	0 to 99	2D beam dispersion on the target, expressed as sigma of a circular normal ("circ") or elliptic normal (=bivariate) probability density function ("xy" = axes of TCS, "uv" = major axis of TCS), due to deviations of the true concentrator shape from the ideal shape for a defined heliostat azimuth/elevation angle + wind + temp. conditions (given in Optics.Beam.BeamQualityConditions) and the focus deviation.The parameter HelioQuality is the convolution of BeamQuality (Optics.Beam.BeamQuality) and Focus Deviation (Tracking.FocusDeviationOnTarget.Focus2D). Additionally to the "circ"-sigma, two further vectors can be given describing the expansion of the beam in direction of two normal axes: Either writing as x/y components (horizontal and vertical target coordinate system TCS axis), or the u/v component (eigen-axis u and eigen-axis v).	The helio quality being the convolution of beam quality (Optics.Beam.BeamQuality) and Focus Deviation (Tracking.FocusDeviationOnTarget.Focus2D) is derived approx. by the formula: HQ,STD = (BQ,STD^2 + Focus,2D,STD^2) ^0.5	IQual
						ERROR COMPONENTS		
166	Optics.ConcErrorComp2D. sigmaSDcontour $\sigma_{SD,contour}$	circ: 1.8 *xy*:[1.4; 1.1]	mrad	string	0 to 99	Measure for the mirror surface accuracy excluding the canting surface error, expressed as sigma of a circular normal ("circ") or elliptic normal (=bivariate) probability density function ("*xy*" = axes of CCS). Originates from deviations of the true to ideal concentrator shape due to the fabrication process or deformations in the centimeter to meter range on the concentrator ("concentrator error"). It is sometimes called waviness surface error if only regular repetitive patterns are observed. The value is valid for the defined heliostat azimuth/elevation angle + wind + temp. conditions given in Optics.Beam.BeamQualityConditions. *xy*: *x/y* components (axes of CCS). Note: As being a concentrator error, these measures have to be given for the concentrator coordinate system CCS (not the target coordinate system TCS).	The contour error of mirror panels can be subtracted from Optics.Conc.SDmat (class-1)	IQual
167	Optics.ConcErrorComp2D. sigmaSDcanting $\sigma_{SD,canting}$	circ: 0.9 *xy*:[0.7; 0.6]	mrad	string	0 to 99	Measure for the mirror surface accuracy, expressed as sigma of a circular normal ("circ") or elliptic normal (=bivariate) probability density function ("*xy*" = axes of CCS). Originates from deviations of the true to ideal concentrator shape due to not perfectly mounted (canted) mirror panels ("concentrator error"). The value is valid for the defined heliostat azimuth/elevation angle + wind + temp. conditions given in Optics.Beam.BeamQualityConditions. Note: As being a concentrator error, these measures have to be given for the heliostat coordinate system CCS (not the target coordinate system TCS).	The canting error of mirror panels can be subtracted from Optics.Conc.SDmat (class-1)	IQual
168	Optics.ConcErrorComp2D. deltasigmaSDgrav $\Delta\sigma_{SD,grav}$	*[-0.1; 0.0; 0.2; 0.3; 0.4] for el=[10 30 50 70 90]°*	mrad	single vector	0 to 99	Measure for the change in mirror surface accuracy, expressed as delta-sigma of a circular normal probability density function, due to additional deformation caused by gravity effects of the concentrator in different elevations, relative to the heliostat orientation defined in Optics.Beam.BeamQualityConditions ("concentrator error"). The value should be given at least for 5 heliostat elevation angles which cover the whole elevation working angles. Interpolation is used to get values for other elevation angles. For detailed geometry information regarding deformation with gravity, see class-1 parameter Optics.Conc.DefGravity_deltaSDmat. Note: As being a concentrator	Can be calculated by using data of Optics.Conc.DefGravity_deltaSDmat (class-1)	IQual

						error, these measures have to be given for the heliostat coordinate system CCS (not the target coordinate system TCS).		
169	Optics.ConcErrorComp2D. deltasigmaSDwind $\Delta\sigma_{SD,wind}$	0.5	mrad	single	0 to 99	Measure for the change in mirror surface accuracy, expressed as delta-sigma of a circular normal probability density function, caused by deformations of the concentrator due to wind loads, relative to the case without wind load ("concentrator error"). An upper limit should be given. The value should be given for this boundary conditions: heliostat elevation=30°, azimuth=0°, situated in the boarder of the field upwind, wind attack angle=30°, windspeed=0.5*WindSpeed.NormalOperation. More information regarding deformation with wind under different boundary conditions, see parameter Optics.Conc.DefWind_deltaSDmat. Note: As being a concentrator error, these measures have to be given for the heliostat coordinate system CCS (not the target coordinate system TCS).	Can be calculated by using data of Optics.Conc.DefWind_deltaSDmat (class-2)	IQual
170	Optics.ConcErrorComp2D. deltasigmaSDtempPerK $(\Delta\sigma_{SD,temp})/\Delta T$	0.02	mrad /K	single	0 to 99	Measure for the specific change in mirror surface accuracy per Kelvin temperature change, expressed as delta-sigma of a circular normal probability density function per Kelvin, caused by deformations of the concentrator due to temperature loads, relative to the reference case (Optics.Conc_2D, "concentrator error"). The value describes the change in mrad per Kelvin temperature difference [mrad/K] compared to the reference case. For detailed geometry information regarding deformation with temperature, see class-1 parameter Optics.Conc.DefTemp_deltaSDmat_perK. Note: As being a concentrator error, these measures have to be given for the heliostat coordinate system CCS (not the target coordinate system TCS).	Can be calculated by using data of Optics.Conc.DefTemp_deltaSDmat_perK (class-1).	IQual
171	Optics.BeamErrorComp2D. sigmaSpecularity σ_{spec}	circ: 0.0 *xy*:[0.0; 0.0] *uv*:[0.0; 0.0]	mrad	string	0 to 99	2D beam dispersion on the target, expressed as sigma of a circular normal ("circ") or elliptic normal (=bivariate) probability density function ("*xy*" = axes of TCS, "*uv*" = major axis of TCS), due to mirror surface accuracy caused to sub-millimeter structures on the reflective surface compared to a perfect mirror without sub-millimeter structures for an incident angle between 0° and 15° ("beam error"). For clean glass mirrors, this value usually is negligible, but not for soiled or actual aluminum mirrors or similar. Note 1: Normally, the effect of the roughness / specularity is already included in the solar weighted spectral reflectance (class-1 parameter Optics.Reflectance. SolarWeightedSpecular). Please also refer to the SolarPACES reflectance guideline. The effect must not be accounted for twice. In addition to the "circ"-sigma, two further vectors can be given describing the expansion of the beam in direction of two normal axes: Either writing as x/y components (horizontal and vertical target coordinate system TCS axis), or the u/v component (eigen-axis *u* and eigen-axis *v*).	Can be determined by recently developed instruments, investigating the beam spread, e.g. Meyen, S., Sutter, F., Heller, P., Oschepkov, A., 2014. A new instrument for measuring the reflectance distribution function of solar reflector materials. Energy Procedia 49, 2145 – 2153 Heimsath, A., Schmid, T., Nitz, P., 2015. Angle resolved specular reflectance measured with VLABS. Energy Procedia 69 1895-1903	IQual
172	Optics.BeamErrorComp2D. sigmaAstigmatism σ_{astigm}	circ: 0.3 *xy*:[0.4; 0.3] *uv*:[0.5; 0.1]; for el_{sun}=80°; az_{sun}=20°	mrad	string	0 to 99	2D beam dispersion and distortion on the target, expressed as sigma of a circular normal ("circ") or elliptic normal (=bivariate) probability density function ("*xy*" = axes of TCS, "*uv*" = major axis of TCS), due to intrinsic departures of any optical system with perfect shape: e.g. astigmatism, coma or image distortion ("beam error"). The values are valid for the defined heliostat azimuth/elevation angle + wind + temp. conditions given in Optics.Beam.BeamQualityConditions. For each set of values, the sun elevation and azimuth have to be given. In addition to the "circ"-sigma, two further vectors can be given describing the expansion of the beam in direction of two normal axes: Either writing as *x/y* components (horizontal and vertical target coordinate system TCS axis), or the *u/v* component (eigen-axis *u* and eigen-axis *v*). The values should be given for 5 sun elevation and 7 sun azimuth angles, that is, in total 5x7 lines with information like (*2D*: 0.3 *xy*:[0.4; 0.3] *uv*:[0.5; 0.1]).	Comparison between 2 focal points, one in on-axis configuration and the other in off-axis configuration. Either using measured images or synthetic images (raytracing)	IQual
						FOCUS DEVIATION ON TARGET		

173	Tracking.FocusDeviationOnTarget .Focus_2D_TCS $Focus2D_{TCS}$	RMS: 0.80	m	string	<10 m	RMS of 2D focus deviation on a beam target in m (in target coordinate system TCS), determined by a continuous position measurement of the beam center. More details regarding test conditions, see Tracking.Accuracy.Track_2D. Note: The focus deviation is in the target coordinate system (TCS) finally indicating performance of the heliostat on a target under specific operation conditions, like slant range, etc. However, the tracking characteristics of the heliostat are better characterized by the Tracking.Accuracy parameters.	see Tracking.Accuracy.Track_2D (class-1 parameter)	IQual
174	Tracking.FocusDeviationOnTarget .Focus_x_TCS $Focus_{x,TCS}$	RMS: 0.75 MEAN: 0.01 STD: 0.75	m	string	<10 m	RMS, MEAN and STD of *x*-component (in target coordinate system TCS) of the focus deviation in m, determined by a continuous position measurement of the beam center. More details regarding test conditions, see Tracking.Accuracy.Track_2D. Note: The focus deviation is given in the target coordinate system (TCS) finally indicating performance of the heliostat on a target under specific operation conditions, like slant range, etc. However, the tracking characteristics of the heliostat are better characterized by the Tracking.Accuracy parameters.	see Tracking.Accuracy.Track_x (class-1 parameter)	IQual
175	Tracking.FocusDeviationOnTarget .Focus_y_TCS $Focus_{y,TCS}$	RMS: 0.75 MEAN: 0.00 STD: 0.75	m	string	<10 m	RMS, MEAN and STD of *y*-component (in target coordinate system TCS) of the focus deviation in m, determined by a continuous position measurement of the beam center. More details regarding test conditions, see Tracking.Accuracy.Track_2D. Note: The focus deviation is given in the target coordinate system (TCS) finally indicating performance of the heliostat on a target under specific operation conditions, like slant range, etc. However, the tracking characteristics of the heliostat are better characterized by the Tracking.Accuracy parameters.	see Tracking.Accuracy.Track_y (class-1 parameter)	IQual

IQual: Independent qualification organization/company; Man = manufacturer