

USER MANUAL **SHR02**

Shadow ring for pyranometers – combined with
a pyranometer forming a diffusometer



Warning statements



Ensure that SHR02 is connected to the protective earth to reduce electrical shock risk and increase instrument operation reliability.



Ensure that the installed pyranometer housing is connected to reduce electrical shock risk and increase instrument operation reliability.

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List of symbols

Quantities

	Symbol	Unit
Global horizontal solar irradiance	E , GHI	W/m^2
In-plane solar irradiance	G_i	W/m^2
Diffuse Horizontal Irradiance	$E_d \downarrow$, DHI	W/m^2
Instrument dome radius	r	m
Shadow ring radius	R	m
Shadow ring rim height	h	m
Shadow ring width	w	m
Shadow ring sliding bar setting	x	m
Correction factor diffuse radiation component	f	-
Latitude of installation	lat	$^\circ$
Solar declination angle	dec	$^\circ$
Hour angle at sunset and sunrise	t_0	$^\circ$
Mathematical constant with a value of 3.14159...	π	-

Subscripts

in-plane portion	i
diffuse portion	d
value at a chosen reference condition	0
obscured portion	obscured
contribution related to instrument dome	dome
contribution assuming symmetrical instrument	symmetrical

Introduction

SHR02 is a practical metal shadow ring that helps making diffuse solar irradiance measurements with pyranometers. The shadow ring, also known as a shadow band, prevents direct radiation from reaching the pyranometer, so that the shaded pyranometer measures diffuse radiation only. The combination of a shadow ring and a pyranometer is called a diffusometer by the ISO 9060:2018 standard. The compact SHR02, combined with a Hukseflux pyranometer, has several advantages over competing models.

SHR02 is compatible with most Hukseflux pyranometers. Hukseflux pyranometers have very low zero offsets, so that the diffuse radiation measurement has a better uncertainty than that of competing pyranometer-shadow ring diffusometers. To avoid problems with dew and frost deposition, the user should consider using the heated SR25 or the heated and ventilated SR30 pyranometer.

A diffuse horizontal irradiance (DHI) measurement with a pyranometer-shadow ring diffusometer is usually combined with a pyranometer-without a shadow ring. The latter measures the global horizontal irradiance (GHI). Combining GHI and DHI with local solar position, the direct normal irradiance (DNI) can be estimated.

Most shadow rings are used with the pyranometer mounted horizontally. The incorporated tilt adjustment stage enables the diffuse irradiance to be measured in a tilted plane. The height of the ring is adjusted manually by adjusting the sliding bars to correct for the changing altitude of the sun.



Figure 0.1 SHR02 shadow ring with a Hukseflux SR30 pyranometer, together forming a diffusometer (a pyranometer is not included in SHR02 delivery).

Using SHR02 has several advantages:

- relatively small size / light weight
- low-investment alternative for a sun tracker with shading-disc
- high accuracy when used with Hukseflux (low zero-offset) pyranometers
- save costs on expensive external ventilation; compatible with SR30 with internal ventilation

Suggested use of SHR02:

- meteorological observations
- building energy performance
- solar energy studies



Figure 0.2 *Installation of the SHR02 shadow ring with a Hukseflux pyranometer is easy.*

The altitude of the sun varies throughout the year and this influences the shadow cast by the shadow ring. Aside from adjusting the shadow ring on a regular basis to compensate for this, it should be taken into account that part of the diffuse radiation obscured by the shadow ring will change. Hukseflux provides a specifically tuned model that will aid the user in setting up the SHR02 without the need for in-depth knowledge of diffusometers. In this user manual a set-up table with required correction factors for the measured diffuse radiation is provided, for a range of latitudes and declinations. The manual also provides theory for creating individual models when even higher accuracy is required.

Compatible sensors are model SR30 and SR15 pyranometers. With the optional mounting adapter, also models SR20, SR22 and SR25 may be used. This user manual covers installation and use of SHR02 with pyranometer models SR30, SR15, SR20, SR22 and SR25.



Figure 0.3 *Pyranometer example: SR15, combined with SHR02 forming a diffusometer.*

1 Ordering and checking at delivery

1.1 Ordering and checking at delivery

The standard configuration of SHR02 is for use with SR15 / SR30 sensor.

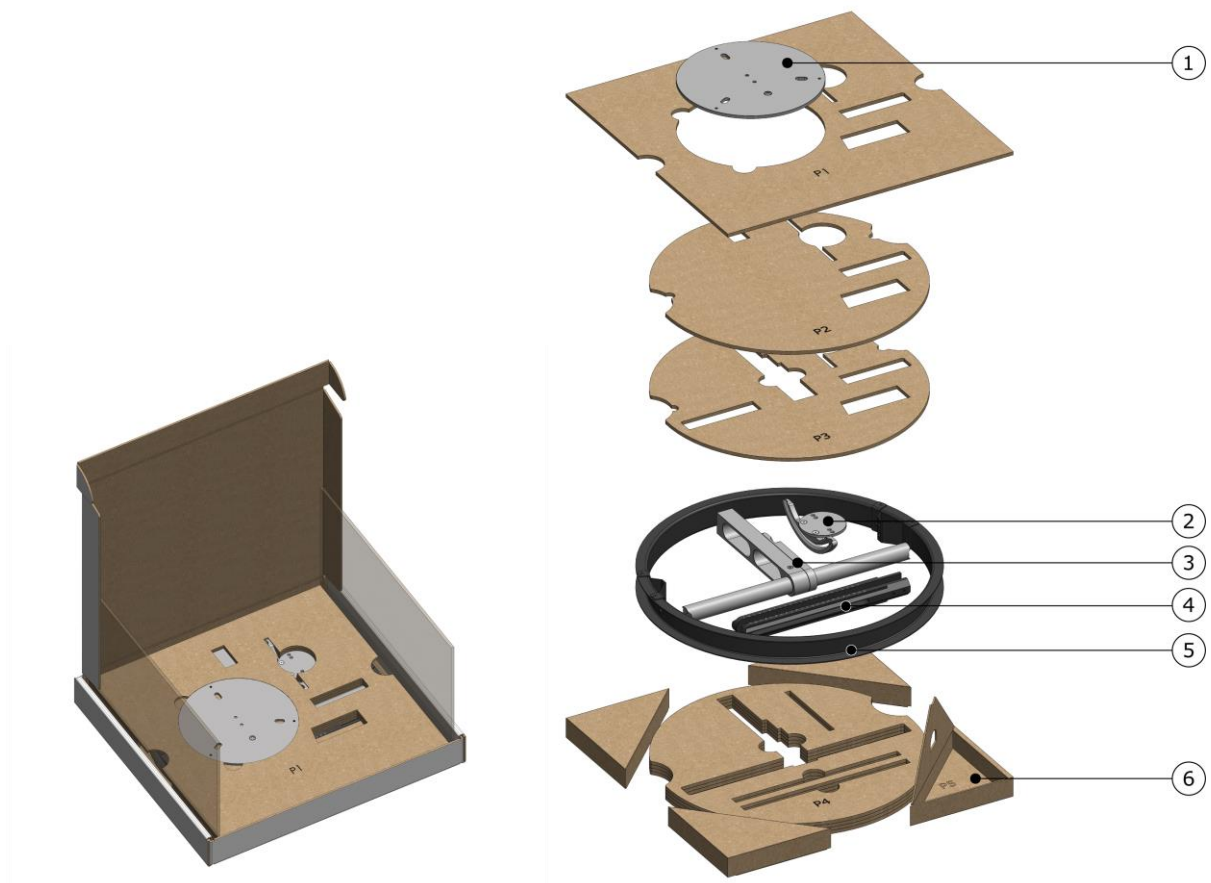
Common options are:

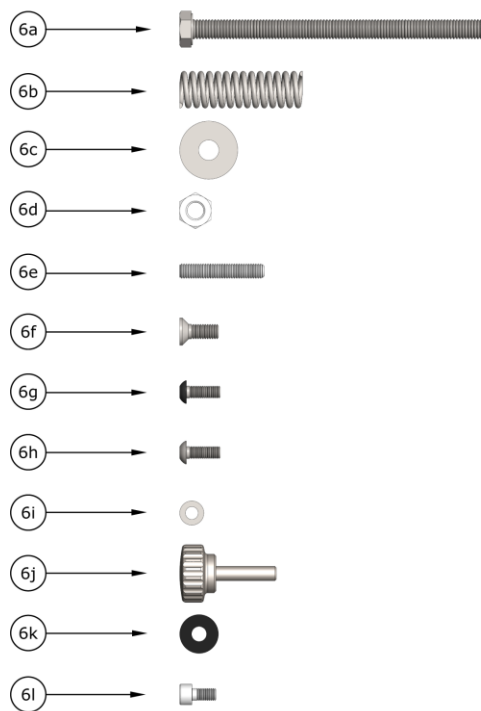
- Mounting adapter for SR20 / SR22 / SR25. Specify PMA01

Table 1.1.1 *Ordering codes for SHR02*

SHR02	Shadow ring for pyranometers, combined with a pyranometer forming a diffusometer (pyranometer is not included in SHR02 delivery)
PMA01	SR20 / SR22 / SR25 mounting adapter for SHR02

1.2 What's in the box





Arriving at the customer, the delivery should include:

1. 1 x base plate
2. 1 x tilt adjustment stage (with engraved rotation scale in °)
with pyranometer mounting plate
3. 1 x central support, horizontal bar connected to pyranometer support arm
4. 2 x sliding bar, with engraved scale in mm
5. 1 x shadow ring
6. 1 x bag with nuts, bolts, set screws:
 - a. 3 x A4 stainless steel M8 x 120 hexagon head bolt
 - b. 3 x A4 stainless steel spring
 - c. 9 x A4 stainless steel M8 washer
 - d. 3 x A4 stainless steel M8 nut
 - e. 3 x A4 stainless steel M6 x 35 flat point socket set screw
 - f. 2 x A4 stainless steel M6 x 16 countersunk socket head cap bolt
 - g. 4 x A4 stainless steel M5 x 14 black button head cap bolt
 - h. 1 x A4 stainless steel M5 x 14 button head cap bolt
 - i. 1 x A4 stainless steel M5 washer
 - j. 2 x A4 stainless steel M6 x 35 thumbscrew
 - k. 2 x Plastic M6 washer
 - l. 2 x A4 stainless steel M5 x 10 socket cap head bolt

1.3 Recommended tooling

For assembling and mounting the shadow ring, the following tooling is recommended:

- hex key 3 mm
- hex key 4 mm
- 2 x spanner 13 mm

For levelling and or adjusting the shadow ring, the following tooling is recommended:

- hex key 3 mm
- hex key 4 mm

Consult your pyranometer user manual for tooling recommended for removal of the pyranometer feet.

2 Instrument principle and theory

2.1 Instrument overview

Figure 2.1.1 below shows SHR02 shadow ring, listing the main functional parts.

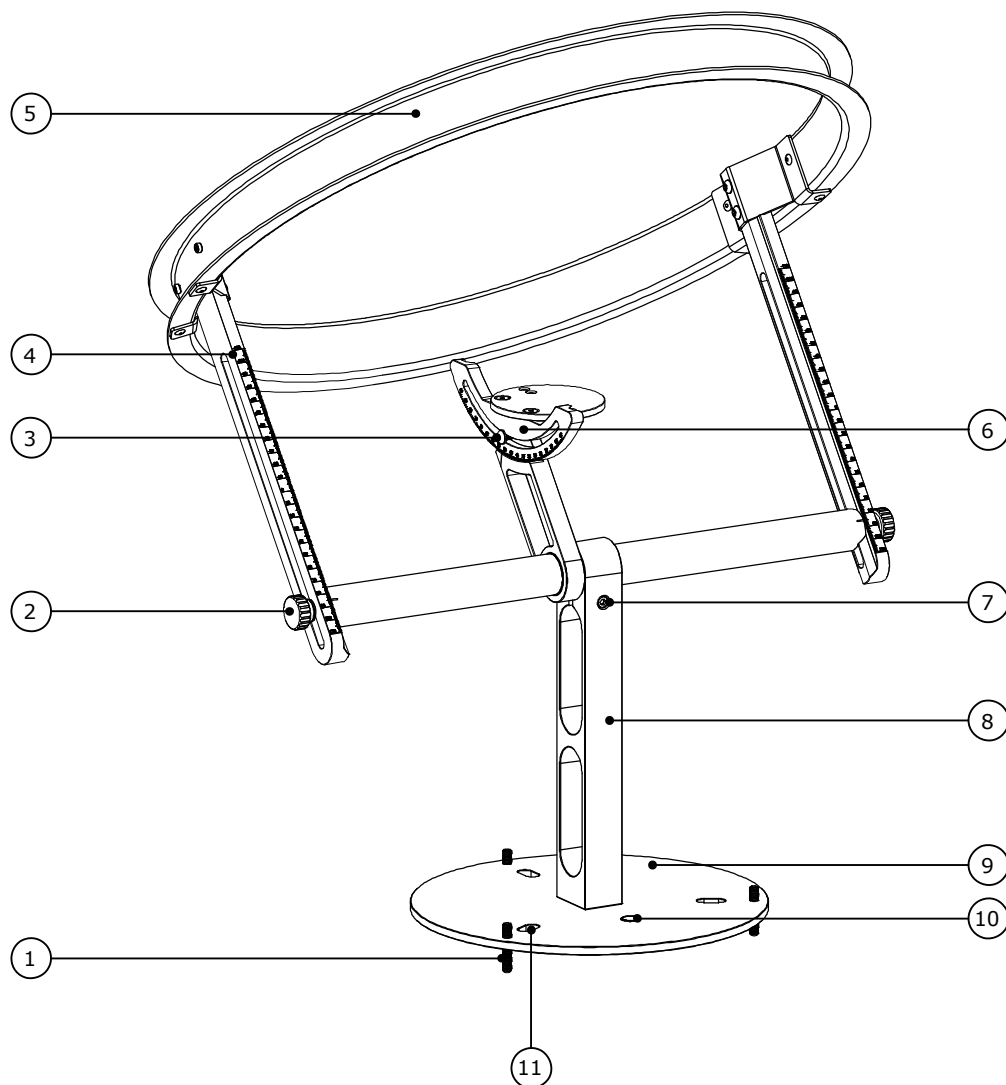


Figure 2.1.1 Overview of SHR02:

- (1) levelling set screw
- (2) thumbscrew for adjustment of sliding bars
- (3) screw for adjustment of tilt stage
- (4) sliding bar
- (5) shadow ring
- (6) tilt adjustment stage
- (7) screw for latitude adjustment
- (8) central support with horizontal bar connected to pyranometer support arm
- (9) base plate
- (10) bubble level
- (11) mounting hole

Understanding the basic set-up, working principles and operation of a shadow ring instrument is essential to attain accurate, reliable measurement data. This chapter describes the basic principles, the main sources of error in data and some practical considerations regarding installation and operation.

A view angle is an important specification for a shadow ring instrument. The view angle is determined purely by the geometrical properties of the ring, assuming the sensitive area of the pyranometer is small compared to the apparent width of the ring. The rims on the ring not only provide mechanical stability but also minimize the seasonal dependence of the view angle on the seasonal variations. The chapter on specifications lists the mean value of the view angle. Due to the ring design, this view angle varies less than 2 % throughout the year, depending on the declination. Note that the correction factors provided in Appendix 8.2 of this manual do not assume this angle to be constant, but take the dependence on the declination into account.

2.2 Operating principles

A shadow ring is used together with a pyranometer to measure diffuse global irradiance. Direct radiation from the sun is blocked by the ring. To achieve this the entire day, the ring is set up parallel to the equatorial plane; see Figure 2.2.1. This is practically done by setting the plane of the ring compared to the horizon under an angle equal 90° minus the local latitude in $^\circ$.

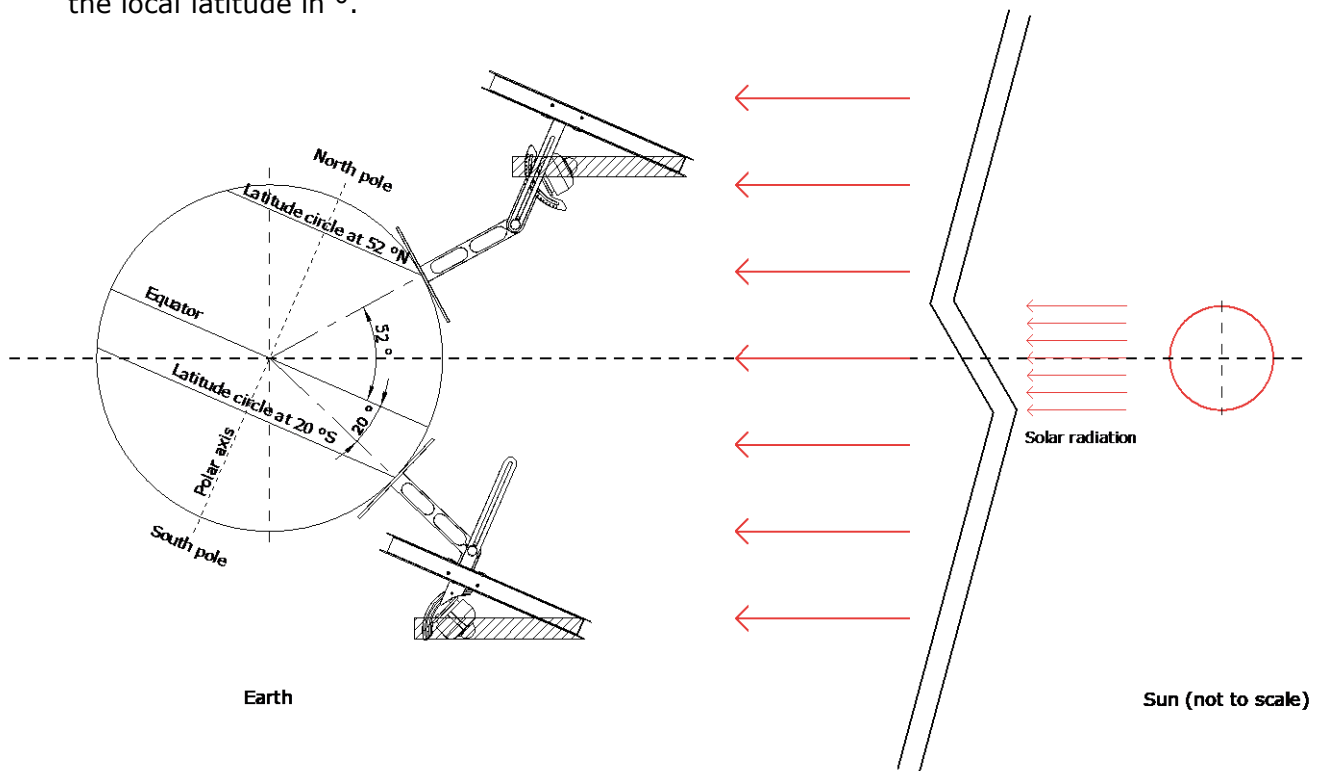


Figure 2.2.1 *The principle of a shadow ring*

During the seasons, the sun's trajectory changes its position in the sky due to variation in the declination of the earth-sun system. The shadow ring is adjusted regularly to block the pyranometer from the sun at all times. Adjustable sliding bars are used to put the

shadow ring in the correct position, compensating for the declination. Figure 2.2.2 schematically explains how a shadow ring is correctly set up. Depending on the time of the year and the local latitude, adjustments need to be made between every day and less than only once every 3 weeks.

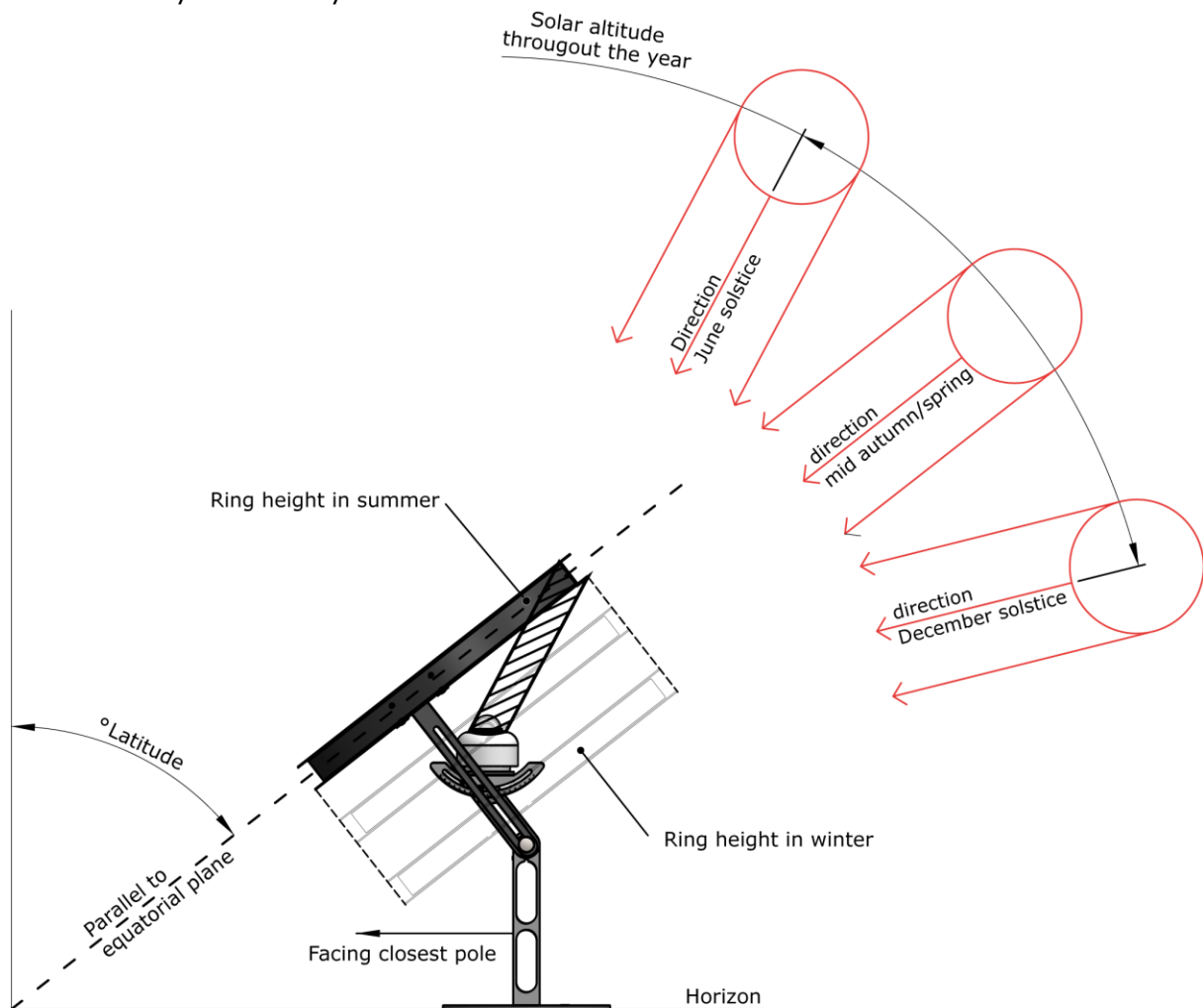


Figure 2.2.2: Regular adjustment needs to be done to compensate for the position of the sun in the sky throughout the year.

Most shadow rings are used with the pyranometer mounted horizontally. Using the incorporated tilt adjustment stage, the pyranometer can also be mounted in a tilted position. In this case, the diffuse irradiance in the tilted plane is measured. To keep the pyranometer shaded, the ring must stay aligned with the equatorial plane.

2.3 Sources of error

There are two main sources of error that may affect the accuracy of the diffuse irradiance component:

- measurement errors
- errors due to unintentional blockage by the ring

Measurement errors, inherent to the type of pyranometer and data logger used, can generally be practically eliminated, but unintentional blockage by the ring is inherent to the instrument operation principle and cannot be avoided. In the next two sections, these sources of error are explained and, if possible, suggestions to remediate them are made.

2.3.1 Unintentional blockage of diffuse radiation

Seen from the centre of the pyranometer, the ring blocks a band of the sky aligned with the trajectory of the sun during the day. Thus, not only the direct radiation from the sun is blocked, but also part of the quantity of interest, the diffuse component. Apart from other possible errors made, this always causes an underestimation of the diffuse irradiance component. In other words, the measured diffuse component is a lower bound for the actual diffuse irradiance component. Depending on the latitude, the declination and the distribution of diffuse radiation, this underestimation is in the range of 5 % to 20 % or even larger.

In an attempt to improve on this and more closely approach the true value of the diffuse irradiance, a correction factor can be calculated or estimated. This correction factor, f , is defined by:

$$DHI = DHI_{\text{observed}} / (1 - f) \quad (\text{Formula 2.3.1.1})$$

with DHI the diffuse radiation and DHI_{observed} the part of the diffuse radiation obscured by the shadow ring. In terms of the corrected and uncorrected diffuse radiation the factor f is given by:

$$f = 1 - DHI_{\text{observed}} / DHI \quad (\text{Formula 2.3.1.2})$$

The simplest possible model to calculate this correction factor assumes a uniform distribution of the diffuse component and computes the fraction of sky that is blocked by the ring, and is also known as the Drummond model. This correction factor depends on the latitude and the declination and is given by:

$$f = 2 (w + h |\tan(\text{dec})|) / (\pi R) \cos^3(\text{dec}) [t_0 \sin(\text{lat}) \sin(\text{dec}) + \cos(\text{lat}) \cos(\text{dec}) \sin(t_0)] \quad (\text{Formula 2.3.1.3})$$

with R the diameter of the ring, h the height of the rims on the ring, w the width of the ring, dec the declination, lat the latitude and t_0 the hour angle at sunset and sunrise. Refer to the specification table in Chapter 4 for the instrument dimensions. For convenience, the table in Appendix 8.2 lists correction factors for a range of latitudes and declinations. There are more sophisticated correction models possible, but these depend on the local conditions and require more assumptions and tuning to local conditions. These models are not discussed here.

2.3.2 Measurement accuracy

A significant error source for diffuse sky radiation measurement is the zero offset of the pyranometer, i.e. the signal at zero irradiation. Under clear sky conditions, the zero

irradiance signal may approach 30 W/m^2 for a second class pyranometer and may be up to 7 W/m^2 for a secondary standard instrument. Since the diffuse irradiance component is typically small, this may be up to 22 % for a second class pyranometer and 5 % for a much more accurate secondary standard instrument under the same conditions. Thus using pyranometers with a low zero offset, such as SR30 or SR25, will result in an improved measurement accuracy. These instrument typically have a zero offset $< 2 \text{ W/m}^2$, resulting in an error in the diffuse component $< 1 \%$. This is the most important source of instrumentation error, but also the data logger accuracy needs to be considered.

Since, as mentioned earlier, the diffuse sky radiation from a cloudless sky is small and may be less than one tenth of the global radiation, relative contribution of pyranometer measurement errors are large. Therefore, particularly in case of an analogue pyranometer, the data acquisition should have a high resolution and small zero offset as well.

2.4 Daily adjustment

The position of the sun in the sky changes depending on the time of the year. To keep the pyranometer shaded by the shadow ring, the position of the ring with respect to the pyranometer is adjusted using the sliding bars. There are different approaches possible to make the correct setting. The simplest, most pragmatic method is to centre the cast shadow around the pyranometer outer dome every day at the time the sun is at its highest point in the sky, at solar noon. This method does require daily attendance and is therefore labour intensive, but may tolerate larger errors in the set-up and alignment of the shadow ring.

An alternative method is to compile a table listing dates and corresponding settings. There are several levels of sophistication possible within this approach. The table in Appendix 8.2 lists a table that can be used at all latitudes and should be seen as a starting point for a pyranometer that is installed horizontally. This table is computed taking the shading effect of the flanges on the ring into account, and attempts to shade the outer dome of the pyranometer for the majority of the time. The formula used to compute this table is:

$$X_{\text{symmetrical}} = (R + h/2) \tan(\text{dec}) \quad (\text{Formula 2.4.1})$$

This equation results in a symmetrical shading around the centre of the pyranometer. In the table, a setting for every 1° in declination is computed. In general, there are two dates during the year at which the declination is the same. To improve on this, the asymmetrical projection of the half-sphere formed by the pyranometer dome can be taken into account as well. Since this projection depends on the angle of the sun with the horizontal this equation depends on the latitude and the declination. Given a setting $X_{\text{symmetrical}}$ the amount x_{dome} can be added to improve the ring adjustment:

$$x_{\text{dome}} = r / 2 (1 - \cos(\text{lat} - \text{dec})) / \cos(\text{dec}) \quad (\text{Formula 2.4.2})$$

with r the diameter of the dome or half-sphere to be shaded. This correction becomes particularly significant at large latitudes and small declinations.

2.5 General usage recommendations

Shadow ring devices must be used according the recommendations of ISO TR9901 paragraph 5.3 “pyranometer for diffuse solar radiation”, and WMO Guide 7.3.3.3 “installation of pyranometers for measuring diffuse sky radiation”. Note that the WMO denotes a shadow ring device as “shading ring”.

Points of attention summarised:

- pay attention to zero offset a of pyranometers;
- carefully set the shadow ring alignment and check the alignment regularly;
- use the appropriate correction factor to correct for the part of the DNI that is obscured by the shadow ring;
- make sure the shadow ring does not cast a shadow on neighbouring pyranometers;
- use data acquisition with high accuracy and low zero offsets

3 Standards and recommended practices for use

Shadow rings and their associated pyranometers must be used in accordance with the recommended practices of ISO, IEC, WMO and / or ASTM.

Pyranometers are classified according to the ISO 9060 standard and the WMO-No. 8 Guide.

3.1 General use for diffuse solar radiation measurement

Table 3.1.1 *Standards with recommendations for instrument use in solar radiation measurement*

STANDARDS FOR INSTRUMENT USE FOR HEMISPHERICAL SOLAR RADIATION		
ISO STANDARD	EQUIVALENT ASTM STANDARD	WMO
ISO/TR 9901:1990 Solar energy -- Field pyranometers -- Recommended practice for use	ASTM G183 - 05 Standard Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers	WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, chapter 7, measurement of radiation, 7.3 measurement of global and diffuse solar radiation
paragraph 5.3 "pyranometer for diffuse solar radiation"		Paragraph 7.3.3.3 "installation of pyranometers for measuring diffuse sky radiation"

3.2 Specific use in meteorology and climatology

The World Meteorological Organization (WMO) is a specialised agency of the United Nations. It is the UN system's authoritative voice on the state and behaviour of the earth's atmosphere and climate. WMO publishes WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, in which a table is included on "level of performance" of pyranometers. Nowadays WMO conforms itself to the ISO classification system.

3.3 Pyranometer classification standard

Table 3.3.1 *Standards for pyranometer classification. See the appendix for definitions of pyranometer specifications, and a table listing the specification limits.*

STANDARDS FOR INSTRUMENT CLASSIFICATION		
ISO STANDARD	EQUIVALENT ASTM STANDARD	WMO
ISO 9060:2018 Solar energy -- specification and classification of instruments for measuring hemispherical solar and direct solar radiation	Not available	WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, chapter 7, measurement of radiation, 7.3 measurement of global and diffuse solar radiation

4 Specifications

4.1 Specifications of SHR02

SHR02 allows making diffuse solar irradiance measurements with pyranometers. In this combination it forms a “diffusometer”. SHR02 should be used in accordance with the recommended practices of ISO, IEC, WMO and ASTM.

Table 4.1.1 *Specifications of SHR02*

SHR02 SPECIFICATIONS	
Function	forming a diffusometer when combined with a pyranometer
Diffusometer measurand	diffuse solar radiation in W/m^2
Diffusometer measurand in SI radiometry units	irradiance in W/m^2
Expected DNI range	0 to 250 W/m^2
Instrument compatibility	SR30, SR15 pyranometers (recommended)
Instrument compatibility	SR25, SR22, SR20 pyranometers (with optional mounting adapter)
Diffusometer zero offset a	with SR30: 2 W/m^2 with SR15: 5 W/m^2 with SR25: 1 W/m^2 with SR20: 5 W/m^2
Use with heating	with SR30 and SR25
Use with ventilation	with SR30
MATERIALS	
Main construction elements	anodised aluminium
Main construction elements, black parts)	anodised aluminium, anaorganic dye
Fasteners	stainless steel A4
DIMENSIONS	
Ring inner diameter	$476 \times 10^{-3} \text{ m}$
Ring rim height	20
Ring width	44
Ring profile	U-profile
Average view angle	10.6°
Ring height/radius ratio	0.185
Maximum diameter shaded area	$40 \times 10^{-3} \text{ m}$
Pyranometer tilt angle range	-90 to 90°
Sliding bar resolution	$1 \times 10^{-3} \text{ m}$
Sliding bar accuracy	$\pm 0.5 \times 10^{-3} \text{ m}$
Sliding bar range	$\pm 110 \times 10^{-3} \text{ m}$
Maximum bounding box height	$770 \times 10^{-3} \text{ m}$
Maximum bounding box depth	$725 \times 10^{-3} \text{ m}$
Maximum bounding box width	$516 \times 10^{-3} \text{ m}$
Horizontal bar height	$246 \times 10^{-3} \text{ m}$
Base plate diameter	$250 \times 10^{-3} \text{ m}$
Net weight	approx. 4 kg
Gross weight (including packaging)	approx. 6 kg
OTHER SPECIFICATIONS	
Rated operating temperature range	-40 to $+80^\circ \text{C}$
Levelling	adjustable levelling screws and bubble level are included, bubble level of SHR02 and of mounted pyranometer are used

Table 4.1.1 *Specifications of SHR02 (continued)*

Bubble level accuracy	< 0.1 ° bubble entirely in ring
Mounting screws	included
Application of correction factors	responsibility of the user (see appendix)
Standards governing use of the instrument	ISO/TR 9901:1990 Solar energy -- Field pyranometers -- Recommended practice for use ASTM G183 - 05 Standard Practice for Field Use of Pyranometers, Pyrhemometers and UV Radiometers WMO-No. 8; Guide to Meteorological Instruments and Methods of Observation, chapter 7, measurement of radiation, 7.3 measurement of global and diffuse solar radiation
INSTALLATION AND USE	
Required adjustment interval	according to adjustment table
Manual adjustment	use the adjustment table in Appendix 8.2 this table refers to the scales which are engraved in the sliding bars
Mounting	follow directions of this manual
Required azimuth (north-south) alignment	1 °
Required zenith alignment (levelling)	1 °
Required latitude alignment of sliding bars	1 °
OPTIONS	
mounting adapter for pyranometer model SR20, SR22, SR25	option code = PMA01

4.2 Dimensions of SHR02

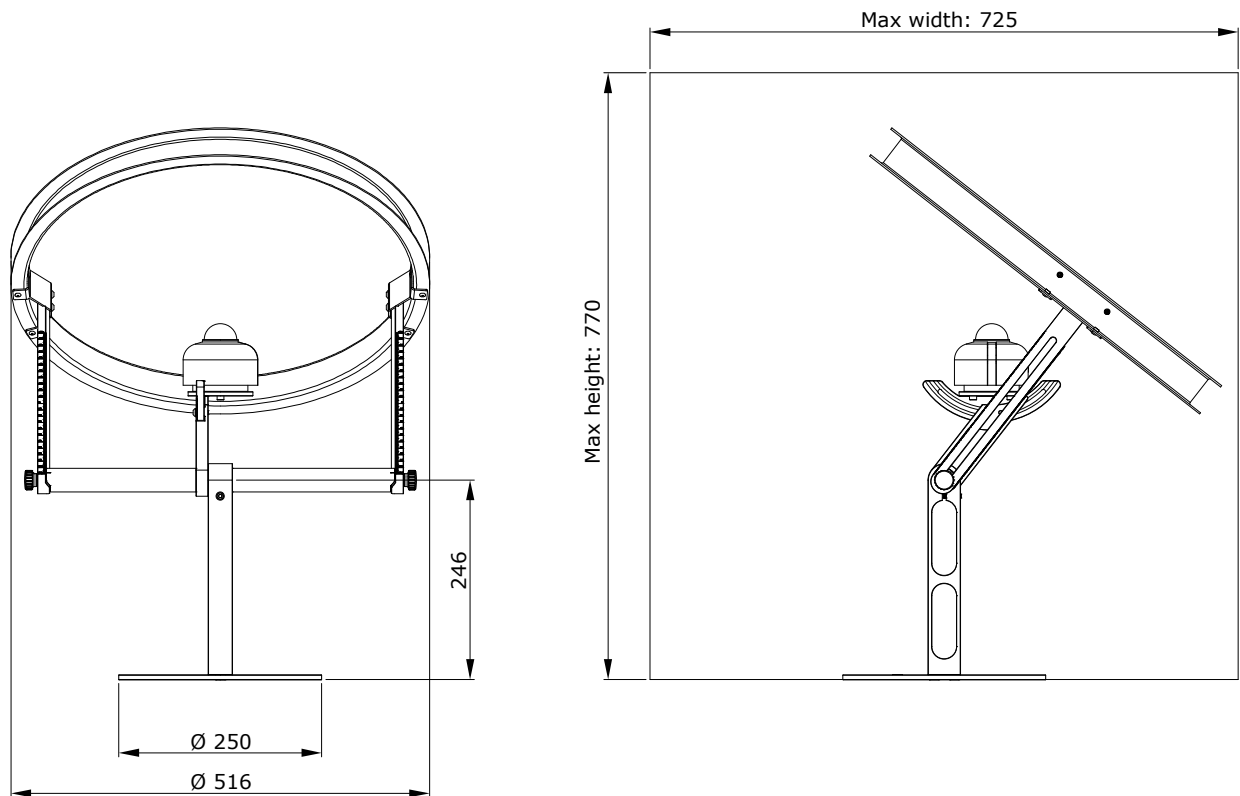


Figure 4.2.1 Dimensions of SHR02 in $\times 10^{-3}$ m. The depicted pyranometer is not included in SHR02 delivery.

5 Installation of SHR02

5.1 Assembly

The shadow ring assembly takes about thirty minutes. Before assembling, ensure that the set is complete; see the chapter on ordering and checking at delivery.

The intended result can be seen on the cover of this manual. An exploded view followed by the recommended assembly steps is shown in Figure 5.1.1. The numbers depicted in the exploded view match the part numbers as described in the What's in the box chapter. The part numbers are referenced throughout the assembly guide, in the format [#], where # is the part number.

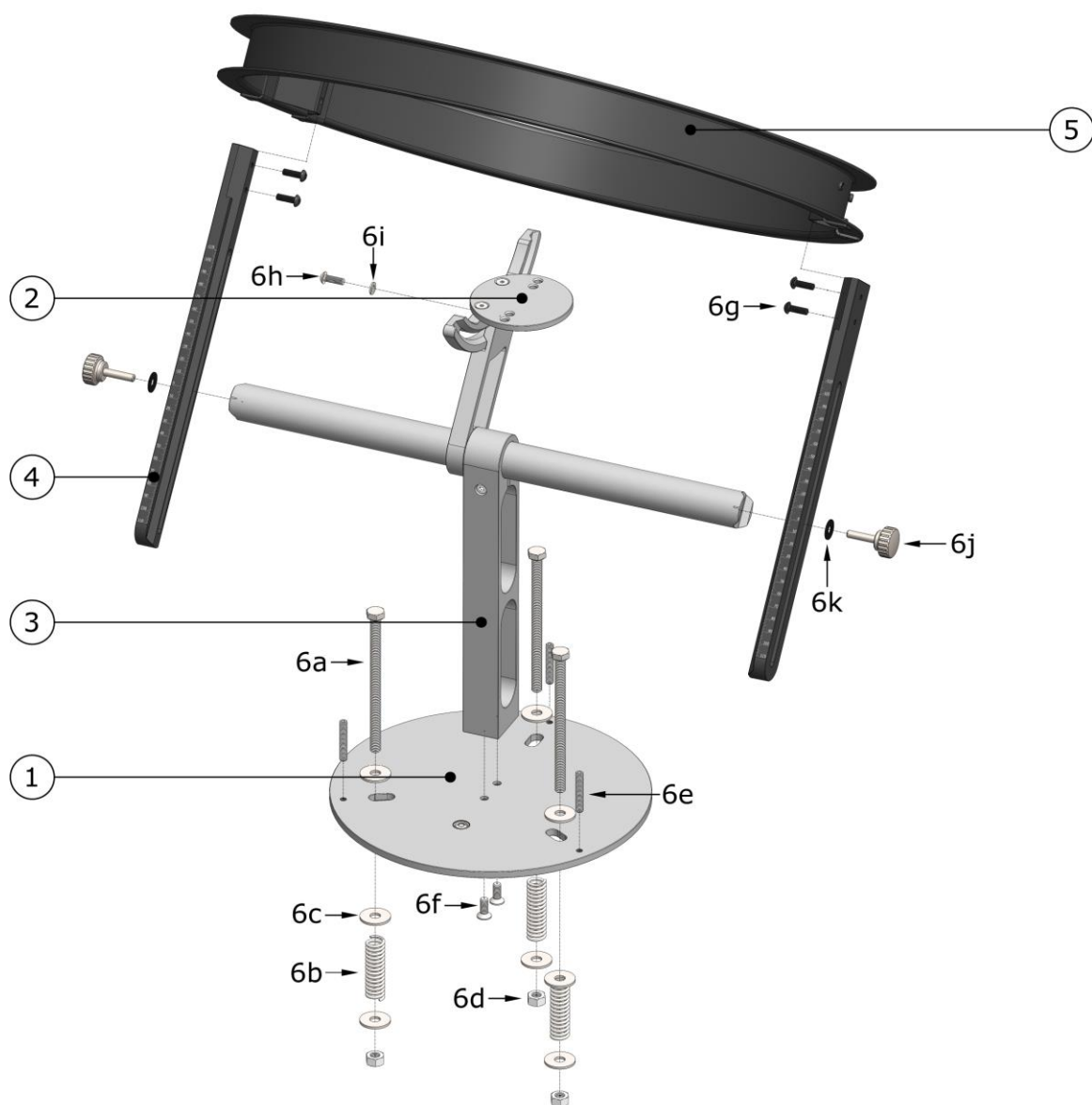


Figure 5.1.1 Exploded view of the SHR02 for assembly overview

5.1.1 Step 1

Take the base plate [1] and the pre-assembled central support with horizontal bar [3]. Fasten the two with 2 x countersunk M6 x 16 mm screws [6f], ensuring that the bubble level on the base plate is facing towards the central support. Fasten the screws with the long end of a 4 mm hex key in the screw to prevent over-tightening and damaging of threads, see Figure 5.2.1.1

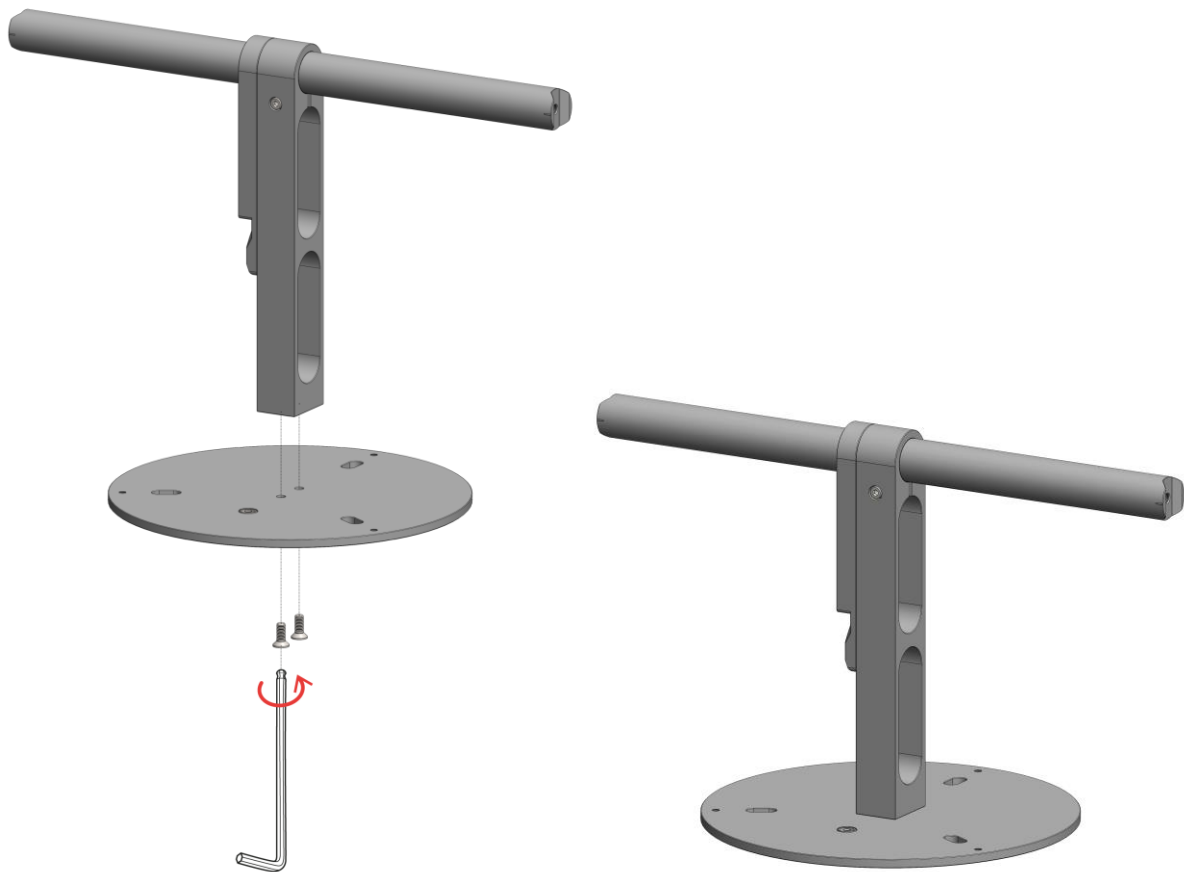


Figure 5.2.1.1 *Assembling the base plate to the central support*

5.1.2 Step 2

Place the assembly of Step 1 on a flat surface. Using a 4 mm hex key, loosen the screw of the clamp in the central support [3] to release the horizontal bar. Turn the horizontal bar so that the in the pyranometer support is in the upright position, and fasten the screw again with the long end of the 4 mm hex key to keep it in place.

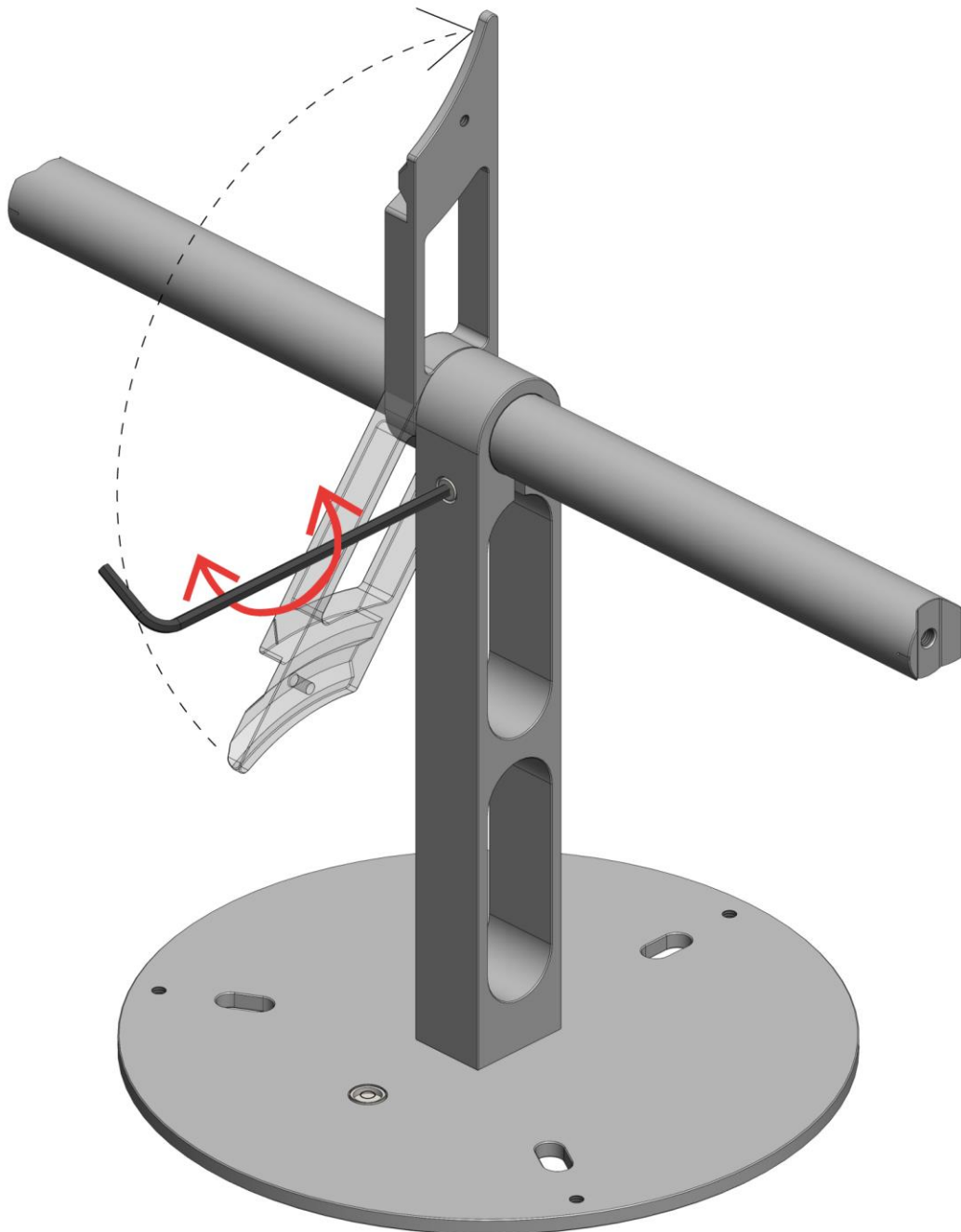


Figure 5.1.2.1 *Adjusting the pyranometer support arm*

5.1.3 Step 3

Attach the tilt adjustment stage with the sensor mounting plate [2] to the pyranometer support that has been pointed upwards in the previous step. Insert the uncoated M5 x 14 mm button socket head cap bolt [6h] with the M5 washer [6i] through the tilt adjustment stage and into the pyranometer support arm. Tighten the screw with the long end of 3 mm hex key.

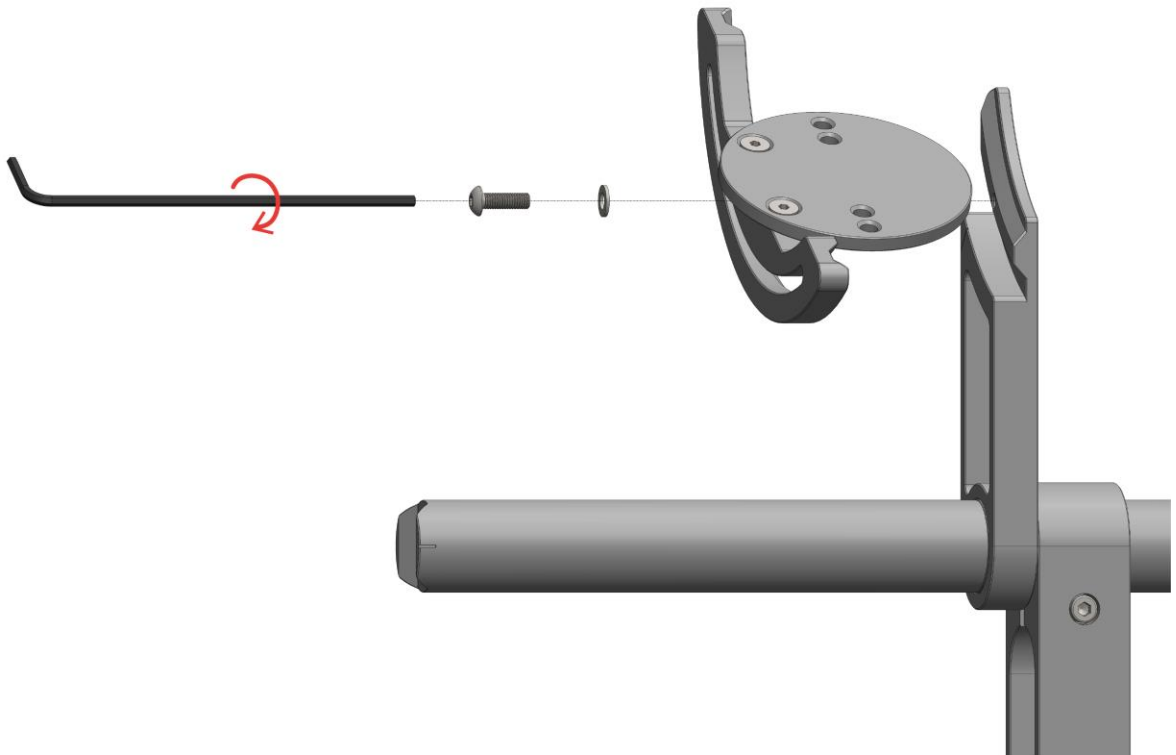


Figure 5.1.3.1 *Attaching the tilt adjustment stage to the pyranometer support arm*

5.1.4 Step 4

Attach the two sliding bars [4] to the ends of the horizontal bar using the thumbscrews [6j] and plastic M6 washers [6k]. The flat end of the sliding bars should point upwards. Adjust the position of the sliding bars so that position '0' aligns with the position marker engraved on the horizontal bar. When in position, lock the sliding bars in place with the thumbscrews.

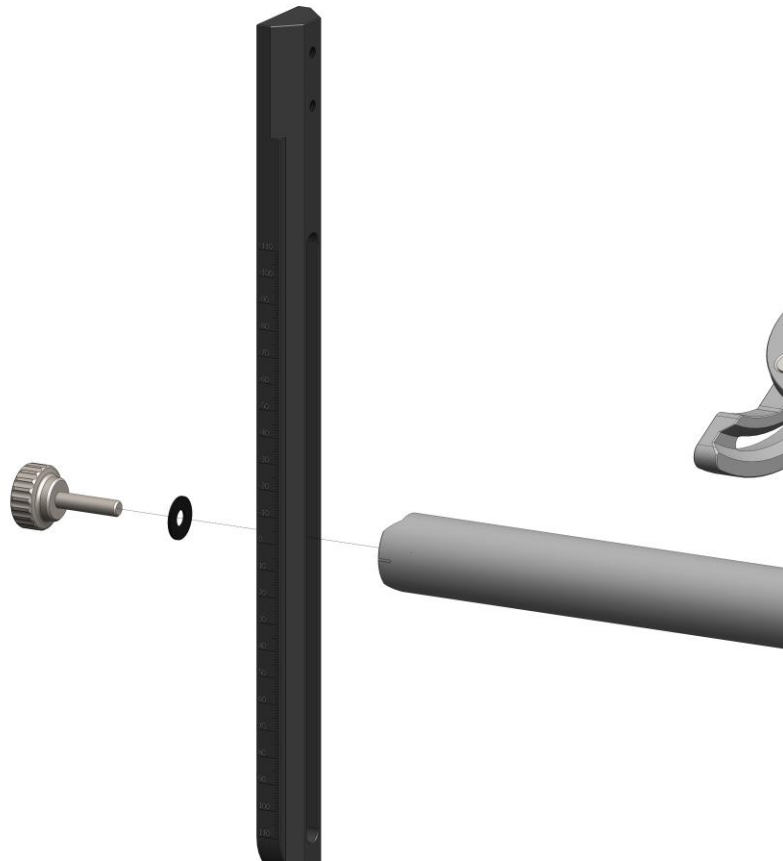


Figure 5.1.4.1 *Attaching a sliding bar to the horizontal bar*

5.1.5 Step 5

The shadow ring [5] has two brackets attached to it. Fit the shadow ring onto the sliding bars [4]. The flanges folding over the shadow ring should be facing downwards. Imagine a line through both brackets; this divides the shadow ring into two areas. The bigger area of the ring should be pointing towards the bubble level on the base plate [1]. Fasten the brackets of the shadow ring to the sliding bars with 4 M5 x 14 mm black button socket head cap bolt [6g] by using the long end of a 3 mm hex key.

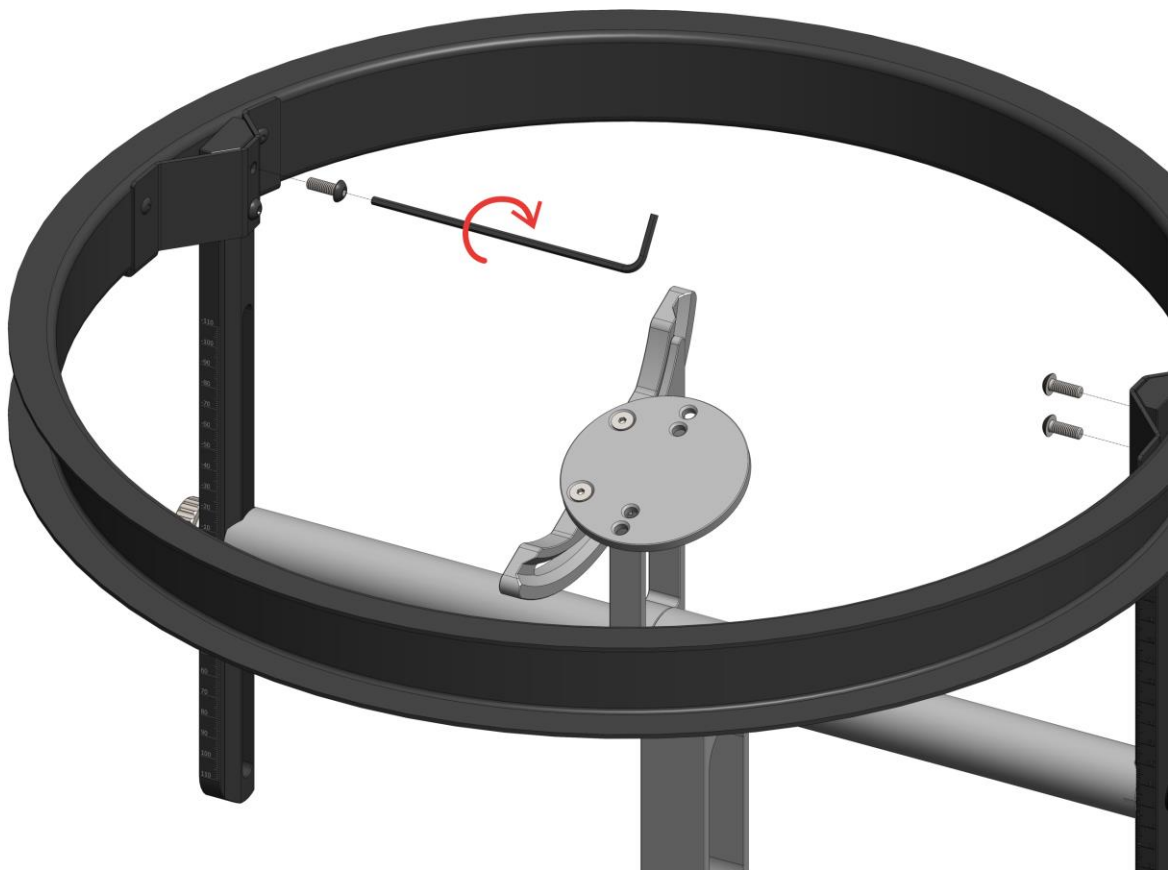


Figure 5.1.5.1 *Attaching the ring to the sliding bars*

The assembly is now complete and should look like in Figure 5.1.5.2.



Figure 5.1.5.2 *The shadow ring when set up correctly*

5.2 Site selection

Follow the general directions in the pyranometer manual. The main requirement is to have a horizon that is as free from obstacles as possible.

5.3 On site mounting

The installation of a pyranometer on a shadow ring is similar to that of a pyranometer which measures GHI. The distance to a neighbouring pyranometer should be sufficient to guarantee that the shading ring does not cast a shadow on it. This may be more difficult at high latitudes where the solar zenith angle can be very low.

Mounting of the shadow ring can be done with the three mounting holes on the base plate. M8 bolts [6a] with springs [6b], washers [6c] and nuts [6d] are included, which are needed for easy levelling.

5.3.1 Hole pattern and relation to azimuth alignment

Before drilling holes or otherwise preparing the mounting platform, make sure the horizontal bar of the instrument can be aligned perpendicular to the true (as opposed to the magnetic) north-south axis. Figure 5.3.1.1 depicts the required orientation. See the next subchapter on alignment for detailed alignment instructions.

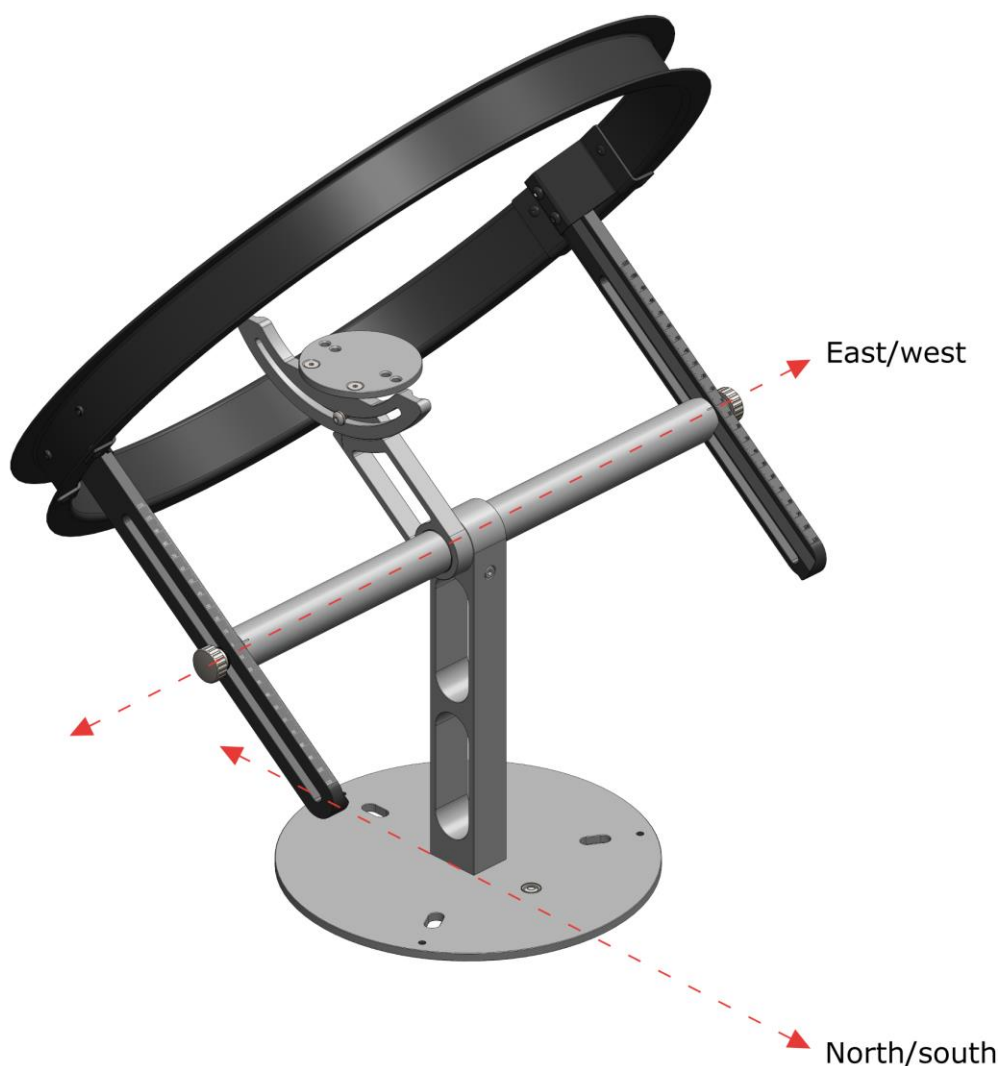


Figure 5.3.1.1 Required orientation of shadow ring

When the correct azimuthal (north-south) orientation is determined, the mounting holes can be drilled. Please refer to the mounting pattern in Appendix 8.1 as a template to scale for proper mounting/drilling, so that SHR02 is installed in the required orientation.

5.3.2 Preferred spring-loaded mounting

The instrument is supplied with mounting bolts [6a], including springs [6b], washers [6c] and nuts [6d]. Recommended mounting is shown in Figure 5.3.2.2. Before mounting the instrument to the mounting platform, insert the three M6 x 35 flat point socket set screws [6e] into the base plate [1]. The screws should be inserted roughly half way into the base plate. Place a washer between the bolt and the base plate [1]. The spring should be attached with washers on both ends. This will keep the spring in place and reduce wear in you mounting platform.

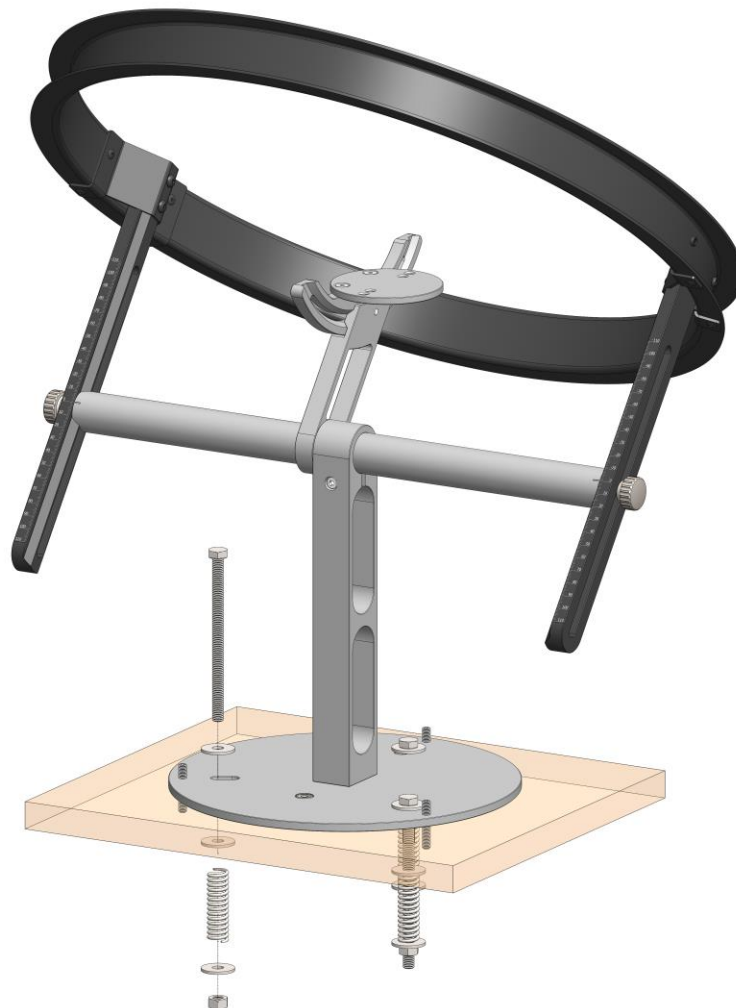


Figure 5.3.2.2 *SHR02 mounting fasteners. For easy levelling of the instrument, insert the bolts pointing downwards. Use the washers as shown to keep the springs in place.*

5.4 Alignment

The shadow ring needs to be aligned so that only diffuse radiation is observed by the pyranometer. Aligning the instrument is done in four steps:

1. azimuthal alignment (north-south orientation)
2. zenithal alignment (levelling)
3. latitudinal alignment (tilt of the shadow ring)
4. solar altitude adjustment (shadow ring height versus the pyranometer)

5.4.1 Step 1: Azimuthal alignment

The highest part of the shadow ring should cast a shadow on the pyranometer when the sun is at its highest altitude of the day. This is obtained by adjusting the azimuth so that the back side (lowest part of the shadow ring) is facing to the nearest pole; the north-south orientation.

The north-south orientation can be obtained using three methods:

- using a map
- using GPS coordinates
- using the sun transit time ("solar noon")

The recommended method is by using a map. This method provides the highest accuracy.

5.4.1.1 Azimuthal alignment using a map

Find your current location on map and mark it on the map. Draw a line directly north or south of that location and try to find an easily distinguishable landmark along that line, but one that is still as far away as possible. Find the landmark in your surroundings and draw an imaginary line from your marked starting point towards the landmark. The shadow ring should be oriented along the found north/south line as depicted earlier in Figure 5.8.1.1. Ensure that the side of the central support, the side with the holes in it, is set parallel to the north/south line. Setting a landmark in the far distance will increase the accuracy of the alignment.

5.4.1.2 Azimuthal alignment using GPS coordinates

This technique can be used when it is hard to find a landmark directly north or south of the location at which the shadow ring should be installed.

Record the GPS coordinates of the location at which the shadow ring will be installed. Find a coordinate north or south from the recorded location that is as far away as possible, but still visible from the starting location. Travel to the set location and place marker that will be visible from the starting location. Travel back to the starting location and draw a line between the starting coordinate and the placed marker. This line should now align with true north/south. The shadow ring should be oriented along the found

north/south line as depicted earlier in Figure 5.3.1.1. Ensure that the side of the central support, the side with the holes in it, is set parallel to the north/south line.

5.4.1.3 Azimuthal alignment using the sun transit time

The sun transit time, also known as solar noon, is the time of day when the sun is reaches it highest position in the sky. At this time, the shadow of the instrument can be used to align itself. At solar transit time, turn the instrument so that the shadow of the vertical central support is parallel to sides of the central support, the sides with the vertical slot. See Figure 5.4.1.3.1 for a render of how the the shadow should align. This method provides a less accurate alignment than the previous methods, since the sun is only at its highest point for roughly two minutes and the referencing line is much shorter than when set out with a map. Besides this, the position of the sun's highest point changes with respect to the earths rotation axis throughout the year according to the "equation of time".



Figure 5.4.1.3.1 *Aligning the shadow parallel to the vertical support*

Note: solar transit time varies with each day and also depends on the location on earth. The most accurate alignment achievable using this method can be attained when performing the alignment during an equinox.

5.4.2 Step 2: Zenithal alignment

After the instrument is assembled, oriented to true north/south and mounted on a platform, it needs to be levelled. To do so, the base plate has three hexagon socket set screws [6e] which can be adjusted with a 3 mm hex key. Adjust the screws until the bubble level next to the vertical support has its bubble in the centre of its inner ring. If the instrument was mounted using the recommended springs, levelling can be done solely by adjusting the levelling screws. If the instrument was mounted without using the recommended springs, loosen the mounting bolts a little to allow movement for levelling. Fasten again after levelling.

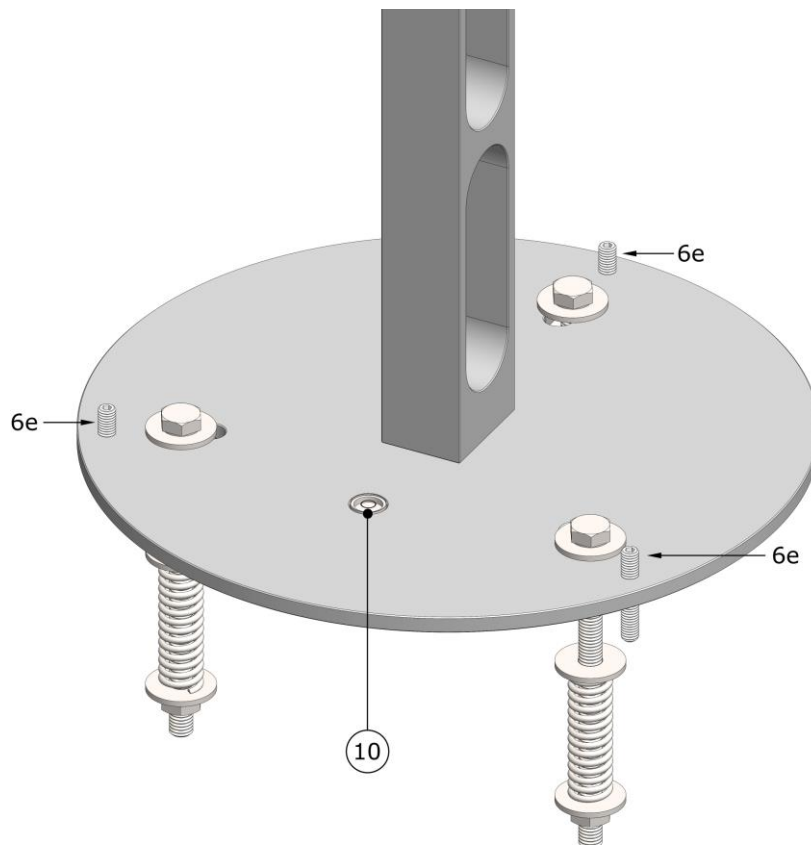


Figure 5.4.2.1 *Levelling the instrument. Set screws [6e], bubble level (10)*

5.4.3 Step 3: Latitudinal alignment

The shadow ring needs to be tilted so that it is parallel to the equatorial plane. The required tilt depends on the latitudinal position on earth. The shadow ring can be set parallel to the equatorial plane by setting the tilt adjustment stage to the corresponding latitude: round the determined latitude to a whole number and set the tilt adjustment stage to that number; see Figure 5.4.3.1.

For example: Delft, the Netherlands is located at 52.0116° N, 4.3571° E . The latitude (North) is 52° , so the rotating tilt adjustment stage should be secured at 52° .

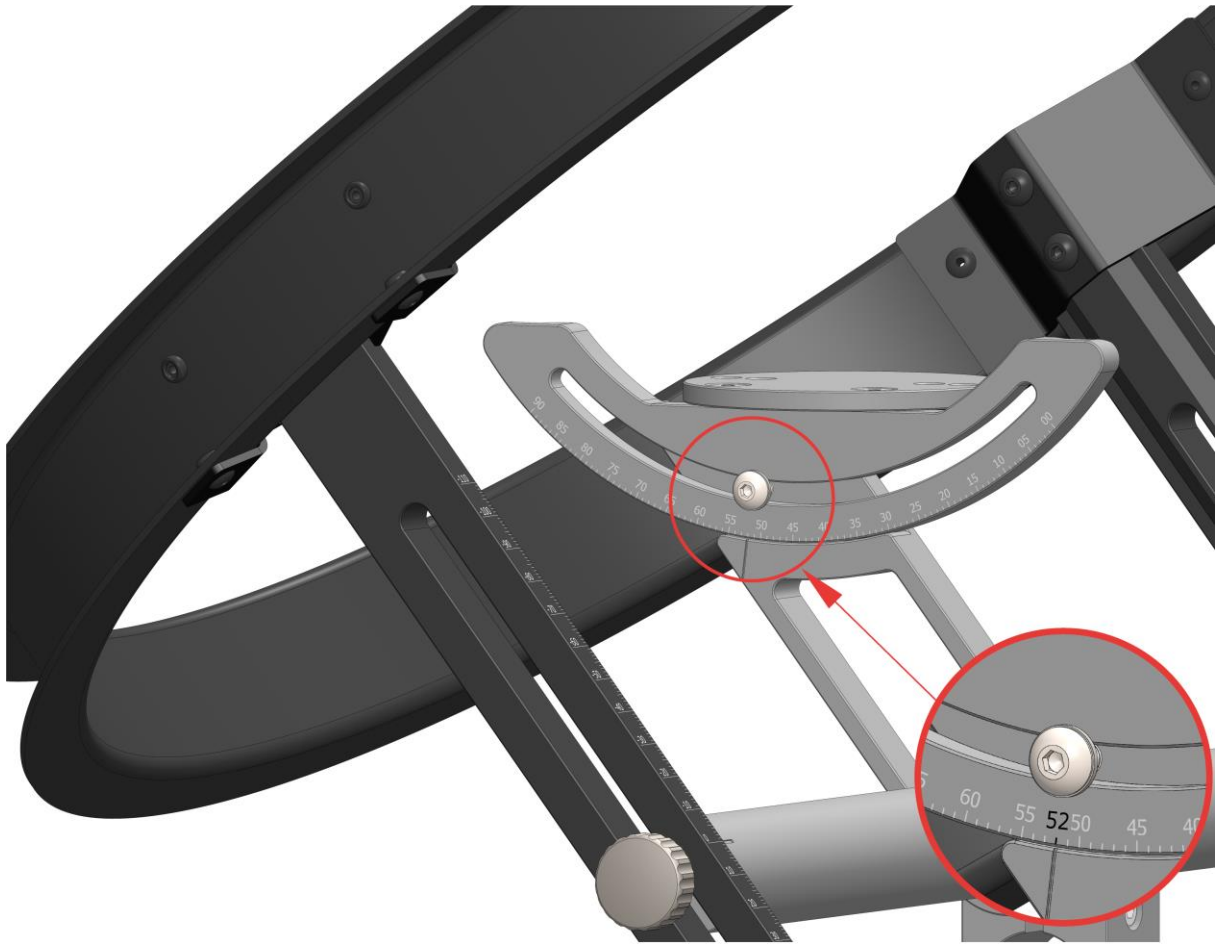


Figure 5.4.3.1 *Setting the tilt adjustment stage to the corresponding latitude*

After setting up a correct latitudinal alignment, the pyranometer should be mounted. The mounting procedure depends on the type of pyranometer. For all types of mounted pyranometers: ensure that the cable of the pyranometer is facing towards the closest pole.

5.4.3.1 Mounting an SR15 or SR30 pyranometer

Remove the feet from the pyranometer before mounting. Mount the pyranometer on the pyranometer mounting plate, which is connected to the tilt adjustment stage [2], and secure the pyranometer with two M5x10 bolts [6i], see Figure 5.4.3.1.1. The bolts should fit into the inner holes in the mounting plate.



Figure 5.4.3.1.1 *Mounting an SR15 pyranometer on SHR02*

5.4.3.2 Mounting an SR20, SR22 or SR25 pyranometer

When mounting an SR20, SR22 or SR25 pyranometer, a mounting adapter is required, which can be ordered separately (see chapter on ordering and checking at delivery).

Remove the feet from the pyranometer before mounting. Mount the pyranometer on the pyranometer mounting plate, which is connected to the tilt adjustment stage [2], and secure the pyranometer with two M5x20 bolts; see Figure 5.4.3.2.1. These bolts are provided with the mounting adapter. The bolts should fit into the outer holes in the mounting plate.



Figure 5.4.3.2.1 *Mounting an SR20 pyranometer on SHR02, using the optional mounting adapter PMA01*

After mounting the sensor, release the bolt on the central support, freeing the horizontal bar for rotational adjustments. Turn the horizontal bar until the bubble level of the pyranometer is level in that axis of rotation. Then, tighten the screw again. See Figure 5.4.3.2.2 for reference.

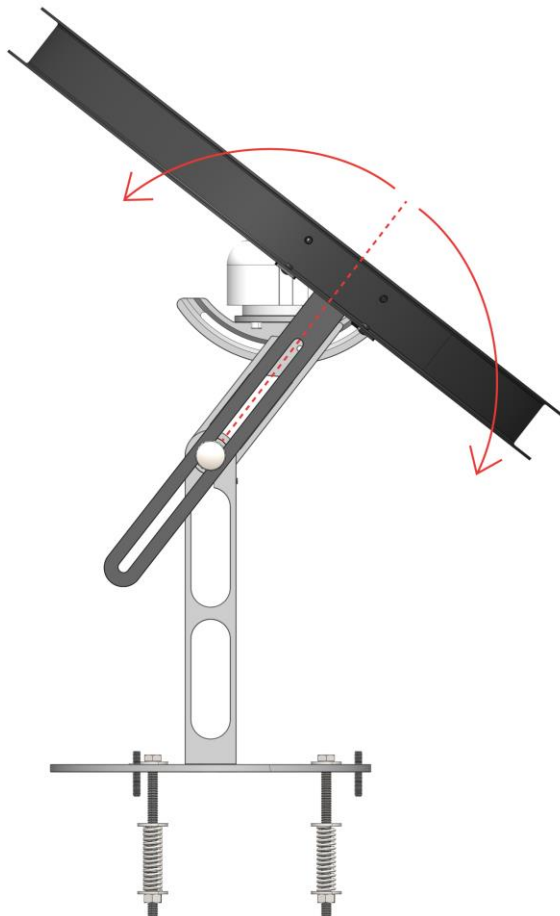


Figure 5.4.3.2.2 *Rotational axis of the horizontal bar for levelling the instrument after placement of the pyranometer*

As a reference for levelling of the entire instrument, use the bubble level on the base plate. Only use the bubble level of the pyranometer for setting the correct latitudinal alignment.

Note: The pyranometer bubble level of secondary standard pyranometers is accurate to 0.1 degrees. This accuracy is not needed when measuring diffuse radiation.

5.4.4 Step 5: day of year adjustment

The maximum altitude of the sun varies throughout the year. The changing angle will cause the shadow created by the shadow ring to vary along with this change. To compensate for this change, the sliding bars can be used to adjust the position of the shadow ring in respect to the pyranometer.

Look up the required setting of the sliding bars corresponding with the day of the year in table in Appendix 8.2. Loosen the thumbscrews and slide the sliding bars to the correct

position. Retighten the thumbscrews to lock the found position. The sliding bars and thumbscrews are designed to prevent the shadow ring from sliding down abruptly when the knobs are loosened simultaneously. This feature prevents damage to the instrument. If the bars seem to be stuck, gently slide one bar back a little, then try again.

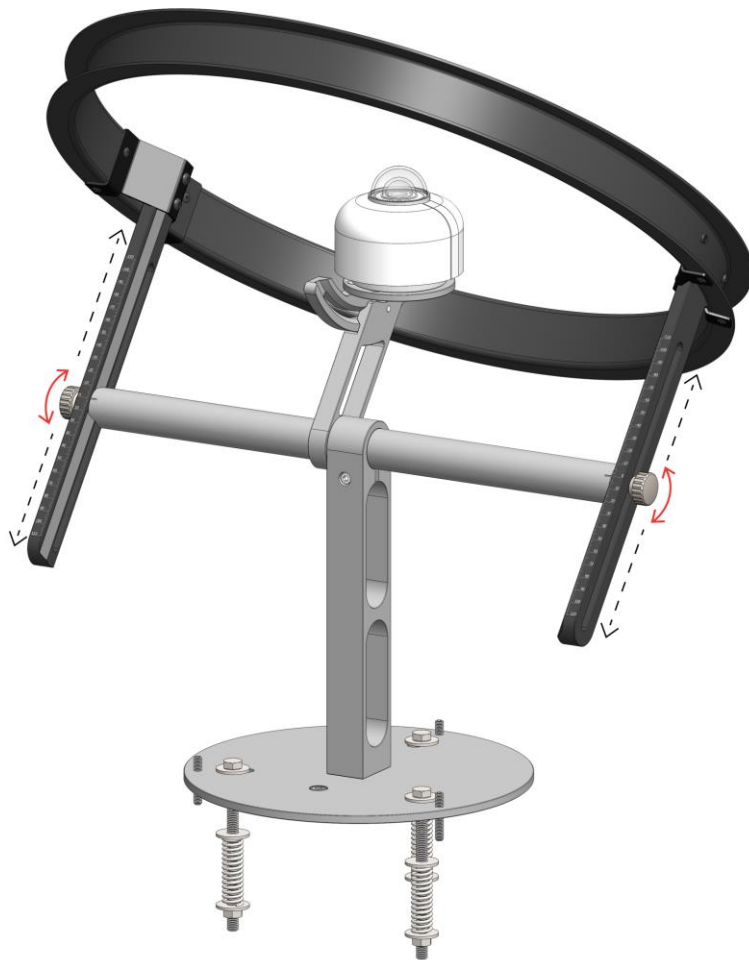


Figure 5.4.4.1 *Sliding the bars to the correct position using the thumbscrews*

6 Maintenance

6.1 Recommended maintenance and quality assurance

For maintenance and trouble shooting of the pyranometer mounted on SHR02, consult the manual of this pyranometer. SHR02 and its pyranometers can measure reliably at a low level of maintenance in most locations. Usually unreliable measurements will be detected as unreasonably large or small measured values. As a general rule this means that regular visual inspection combined with a critical review of the measured data, preferably checking against other measurements, is the preferred way to obtain a reliable measurement.

Table 6.1.1 *Recommended maintenance of diffusometers. If possible the data analysis and cleaning (2 and 3) should be done on a daily basis.*

MINIMUM RECOMMENDED PYRANOMETER + SHADOW RING MAINTENANCE			
	INTERVAL	SUBJECT	ACTION
1	according to adjustment table	manual adjustment	adjust sliding bars
2	1 week	data analysis	compare measured data to maximum possible / maximum expected diffuse DNI irradiance and to other measurements nearby (redundant instruments). Use correction factors for DHI. Compare to GHI measurements. Also historical seasonal records can be used as a source for expected values. Analyse night time signals. These signals may be negative (down to - 5 W/m ² on clear windless nights), for most pyranometers, less for Hukseflux SR25 and SR30 due to zero offset a.
3	2 weeks	cleaning	use a soft cloth to clean the dome of the pyranometers, persistent stains can be treated with soapy water or alcohol
4	6 months	inspection	Inspect shadow ring mounting + alignment inspect cable quality, inspect connectors, inspect mounting position, inspect cable, clean instrument, clean cable, inspect levelling, change instrument tilt in case this is out of specification, inspect mounting connection, inspect interior of dome for condensation
5	2 years	pyranometer recalibration	recalibration by side-by-side comparison to a higher standard instrument in the field according to ISO 9847 request "power user" status and a password at the factory permitting to write to registers holding the sensitivity and the calibration history data via the Sensor Manager (digital sensors)
6	> 5 years	desiccant replacement	desiccant replacement. Typically during calibration desiccant is replaced. Ask the manufacturer for directions
7		lifetime assessment	judge if the instrument should be reliable for another 2 years, or if it should be replaced
8		parts replacement	if applicable / necessary replace the parts that are most exposed to weathering; cable, connector. NOTE: use Hukseflux approved parts only

7 Trouble shooting

For maintenance and trouble shooting of the pyranometer mounted on SHR02, consult the manual of this pyranometer. SHR02 and its recommended pyranometers can measure reliably at a low level of maintenance in most locations. Usually unreliable measurements will be detected as unreasonably large or small measured values. As a general rule this means that regular visual inspection combined with a critical review of the measured data, preferably checking against other measurements, is the preferred way to obtain a reliable measurement.

7.1 Irradiance level too high

Expected DNI levels are between -10 (zero offset) and 250 W/m². In case the measured irradiance is too high, the shadow ring might be above or below the perceived trajectory of the sun. The following can be done to ensure the instrument is properly aligned:

- go the site and see what occurs
- consult your adjustment scheme and check if the sliding bars are set at the correct setting for the day of the year
- check if the rotating tilt adjustment stage is set to the correct latitude of its position on earth
- check if the instrument is aligned properly to true north/south (see Appendix 8.2)
- it is not aligned 180 degrees turned

7.2 Alignment errors

Alignment errors can cause the shadow ring to not fully obstruct direct solar radiation from reaching the pyranometer. This will result in measuring higher irradiance levels than the actual diffuse solar radiation. Expected DNI levels are between -10 (zero offset) and 250 W/m². Regular inspection of the shadow ring ensures that the instrument is set up correctly.

7.2.1 Incorrect azimuthal alignment

As is explained in Chapter 2.3.2 and 5.4.1, it is important that the shadow ring has proper azimuthal alignment (aligned correctly to the north/south axis). If there are large errors in orientation, the alignment error will be easily visible at the sun transit time. If the shadow ring is properly aligned, the shadow cast by shadow ring should look as shown in Figure 7.2.1.1.

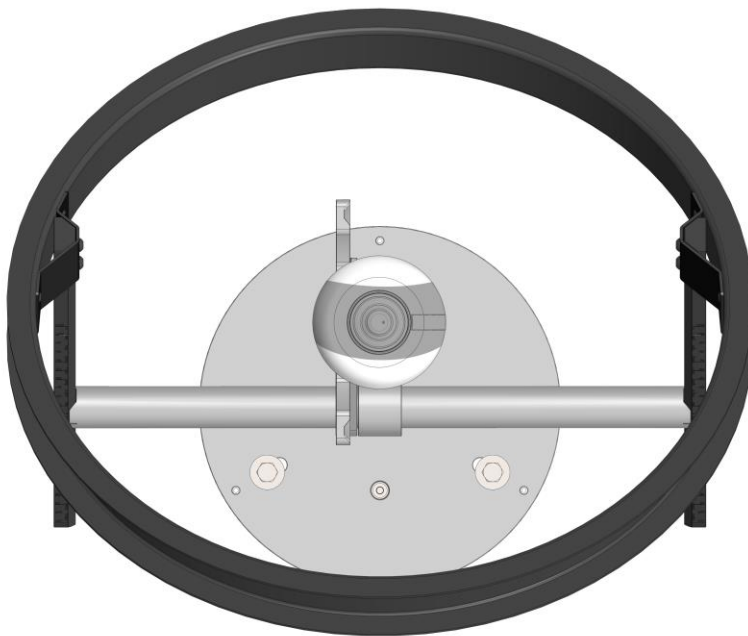


Figure 7.2.1.1 *Shadow cast by the shadow ring when correctly aligned*

If the azimuthal alignment is off by a few degrees or more, the tangent at the symmetry plane (through the centre of the dome) of the cast shadow will not be parallel to the horizontal bar; see Figure 7.2.1.2. For small angles, $< 5^\circ$, it will be hard to judge if the shadow is parallel, so this method will only be useful to detect large alignment errors. Also, the tangent of the shadow can only be perfectly parallel during an equinox.

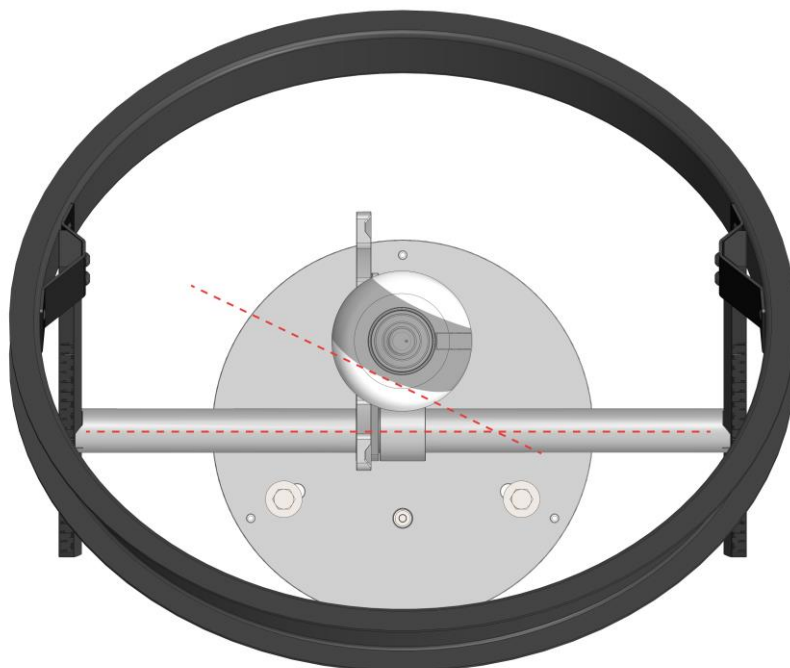


Figure 7.2.1.2 *Tangent to cast shadow should be parallel to axle*

7.2.2 Incorrect zenithal/latitudinal alignment

As is explained in Chapter 2.2 and 5.4.3/5.4.4, the ring of the shadow ring has to be set parallel to the equatorial plane. In a normal, non-tilted set-up, the pyranometer should be level. This can be adjusted by setting the tilt adjustment stage. Errors in this set-up are hard to detect by observing the shadow ring. To ensure correct alignment, run through chapter 5.4.3 and 5.4.4 again.

7.2.3 Incorrect day of year adjustment

As is explained in Chapter 2.2 and 5.4.4, the shadow ring will have to be adjusted regularly using the sliding bars to compensate for the change in solar altitude. To check if the sliding bars are set correctly, refer to figure 7.2.3.1 and 7.2.3.2; the shadow should be cast to envelope the entire outer dome of the pyranometer. This can best be judged during solar transit time, as the shadow will turn around the pyranometer during the day, making it hard to distinguish azimuthal, zenithal/latitudinal errors from errors in the sliding bar setting.

During solar transit time, a shadow as shown in Figure 7.2.3.1 shows that the sliding bars are set too high, casting the shadow further away over the pyranometer. Figure 7.2.3.2 shows the shadow when the sliding bars are set too low.

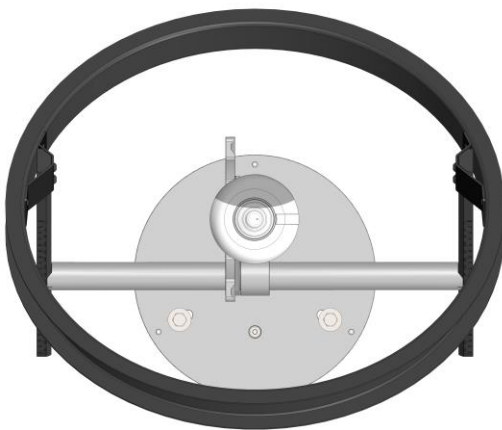


Figure 7.2.3.1 *Sliding bars set too high*

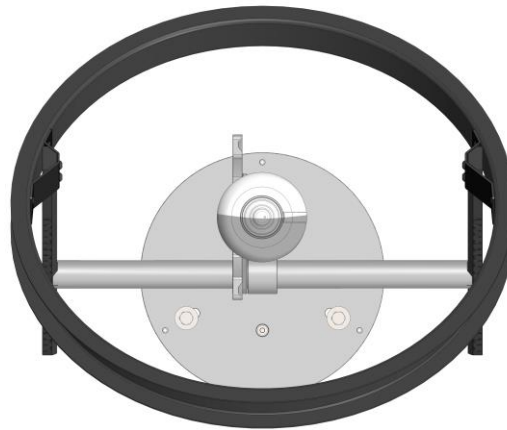


Figure 7.2.3.2 *Sliding bars set too low*

8 Appendices

8.1 Mounting pattern

