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INTERNATIONAL STANDARD

colour inside

Flexible display devices –
Part 6-22: Crease and waviness measurement methods

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FLEXIBLE DISPLAY DEVICES –

Part 6-22: Crease and waviness measurement methods

FOREWORD

IEC 62715-6-22 has been prepared by IEC technical committee 110: Electronic displays. It is an International Standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
110/1491/FDIS	110/1503/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62715 series, published under the general title *Flexible display devices*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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INTRODUCTION

The market for foldable display devices is growing rapidly, as shown in the new form factors for portable devices. It is expected that various foldable display devices will be released in the near future.

Typically, the cover for rigid displays is made of glass. A rigid glass cover protects the display panel from external shock and produces a surface uniformity without visual distortion. In order to utilize a foldable display, a thin and flexible cover is preferred rather than the thick general rigid cover. Although cover materials like thin films or plastics can be flexible, their surface is rougher and can crease more easily. Based on this expectation, there is an anticipation to standardize the measurement of surface creasing and waviness due to folding in order to evaluate the surface quality of foldable displays.

There is a wide variety of ways to analyse the surface of an object, and many of them are already standardized, [1] to [9][1]. In this document, two of the non-contact methods and one contact method using a probe are described, and the manner in which to report the values of crease and waviness of foldable displays from the measured data is specified.

1 Numbers in square brackets refer to the Bibliography.

FLEXIBLE DISPLAY DEVICES –

Part 6-22: Crease and waviness measurement methods

1 Scope

This part of IEC 62715 specifies the standard measurement conditions and methods for determining the surface crease and waviness for the evaluation of foldable displays. The measurement methods are used to specify the extent of geometrical distortions in foldable display surfaces. This document applies to foldable display panels and modules (e.g. in-folding and out-folding) with one axis.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-845, *International Electrotechnical Vocabulary (IEV) – Part 845: Lighting* (available at <http://www.electropedia.org>)

IEC 62341-1-2, *Organic light emitting diode (OLED) displays – Part 1-2: Terminology and letter symbols*

IEC 62341-6-2:2015, *Organic light emitting diode (OLED) displays – Part 6-2: Measuring methods of visual quality and ambient performance*

IEC 62715-5-3, *Flexible display devices – Part 5-3: Visual assessment of image quality and defects*

IEC 62715-6-1, *Flexible display devices – Part 6-1: Mechanical test methods – Deformation tests*

ISO 4287, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters*

ISO 16610-21, *Geometrical product specifications (GPS) – Filtration – Part 21: Linear profile filters: Gaussian filters*

ASME B46.1-2019, *Surface Texture (Surface Roughness, Waviness, and Lay)*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62341-1-2 and IEC 60050-845 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
crease
permanent or temporary linear visual distortion or deformation in the screen due to folding

3.1.2
waviness
long wavelength variation in a surface away from its basic form

Note 1 to entry: Within small areas of the display, distortions can occur in what should be nominally straight features in images, characters, and symbols. This measurement characterizes the deviations from straightness.

3.1.3
folding area
curved section of the panel due to folding

3.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

CCD	charge-coupled device
CMM	coordinate measuring machine
CMOS	complementary metal-oxide semiconductor
DUT	devices under test
LIDAR	light detection and ranging
PMD	phase measuring deflectometry
PSD	position sensitive detector

4 Standard atmospheric conditions

The standard atmospheric conditions specified in IEC 62715-6-1 shall apply as follows, unless otherwise specifically agreed between customer and supplier:

- temperature: 25 °C ± 3 °C
- relative humidity: 25 % RH to 85 % RH
- atmospheric pressure: 86 kPa to 106 kPa

The temperature and humidity conditions shall be reported.

5 Preparation of specimen for measurement

5.1 General

In this document, the measurement object is called specimen, and the specimen consists of foldable panel, modules, adhesive, base plate and jig. The description of the specimen's components and how to configure them is specified in 5.3. All measurements shall be performed under non-operating conditions.

5.2 Visual examination

The foldable display panel is subjected to visual and dimensional checks under non-operating conditions and a functional check under operating conditions specified as follows:

a) non-operating conditions: visual damage on the surface of the specimen shall be checked;

b) operating conditions: visual assessment shall be done by the methods specified in IEC 62715-5-3.

Unless otherwise specified, visual examination shall be performed under the conditions and methods specified in IEC 62341-6-2:2015, 5.2.2.1.

NOTE The purpose of 5.2 is to check the surface damage or failure of the DUT before performing the measurement.

5.3 Specimen preparation

The conditions for the preparation of the specimen (e.g. plate, jig, number of cyclic folding tests, folding duration time) and its size shall be determined between the supplier and customer.

If a mechanical test (e.g. cyclic folding test) is performed in the process of preparing the specimen, the mechanical test method and condition shall be determined between the supplier and customer before the preparation of the specimen. This mechanical test specified in IEC 62715-6-1 and the test method and condition shall be reported.

NOTE 1 If the mechanical test is not performed in the process of preparing the specimen, the corresponding content in Table 1 will be empty.

The temperature, humidity, storage time prior to testing, and the delayed time between the specimen preparation and measurement can affect the crease and waviness, so the specimen preparation condition and delayed time shall be controlled and reported.

NOTE 2 If the foldable display panel is unfolded and the time is delayed, the measurement result of the crease and waviness can be smaller or alleviated due to the resilience of the panel. Therefore, the delayed time will be reported as illustrated in Table 1.

The order and process of preparing the specimen are described as illustrated in Figure 1, Figure 2, Figure 3, and Figure 4.

a) Step 1: Preparing the components of the specimen: The foldable display panel should be unfolded after a specific duration time under the conditions which are reported in Table 1. The base plate shall be flat and bigger than the foldable display panel. The jig with a flat surface should be fixed to the base plate and have an adhesive on the top attached to the back of the panel. The panel holder is used to prepare the out-folding type panel. It is a tool to maintain the flatness of the panel while the jig is attached to the back of the panel in step 2 and step 3. The height of the panel holder should be high enough that the folding area does not touch the ground when the out-folding type panel is placed on it.

NOTE 3 Once the jig and the panel are attached, the panel holder is no longer necessary.

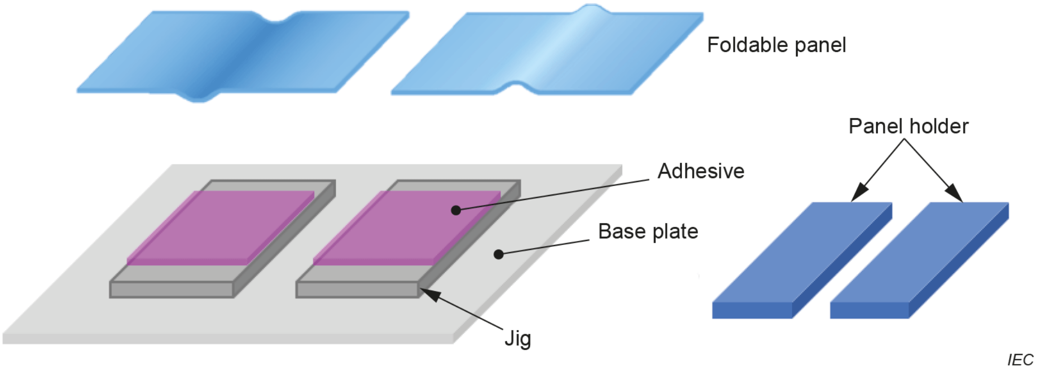


Figure 1 – Step 1: Preparing the components of the specimen

b) Step 2: Turning the back of the panel to face upward: The method and location of the attachment should not affect the measurement. In order to eliminate the influence of tensile tension that can occur in the process of attaching the panel to the jig, the foldable panel shall be flipped so that the back of the panel faces upward. In other words, as shown in Figure 2, the light emitting surface of the panel is placed downward.

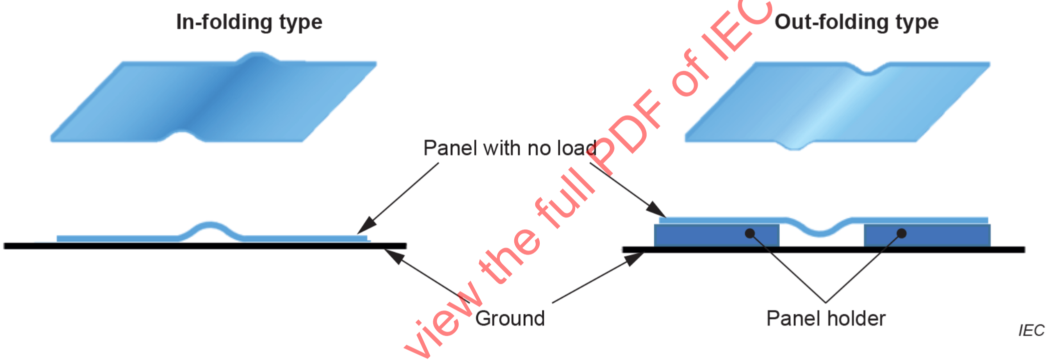


Figure 2 – Step 2: Turning the back of the panel to face upward

c) Step 3: Turning over the base plate and attaching it to the back of the panel. The base plate shall also be flipped so that the adhesive surface faces downward. Then, lower the base plate from the top down and attach it to the back of the panel.

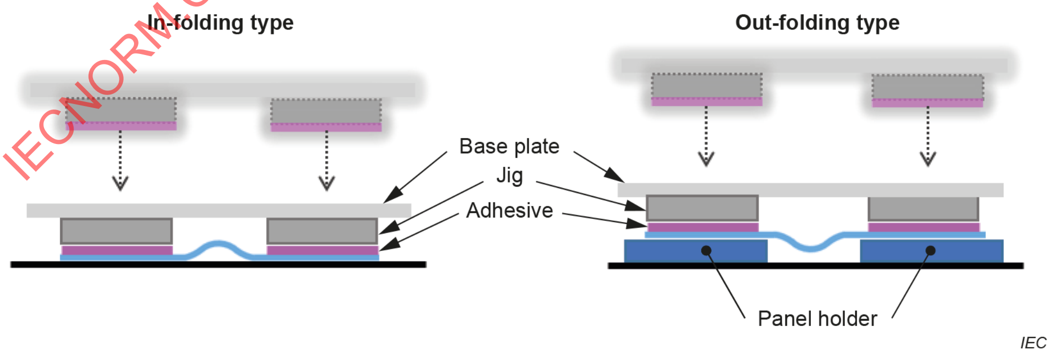


Figure 3 – Step 3: Turning over the base plate and attaching it to the back of the panel

d) Step 4: Turning over the base plate with the panel attached. When the base plate with the foldable panel attached is turned over, the top of the panel to be measured faces upward and the specimen preparation is complete, as shown in Figure 4.

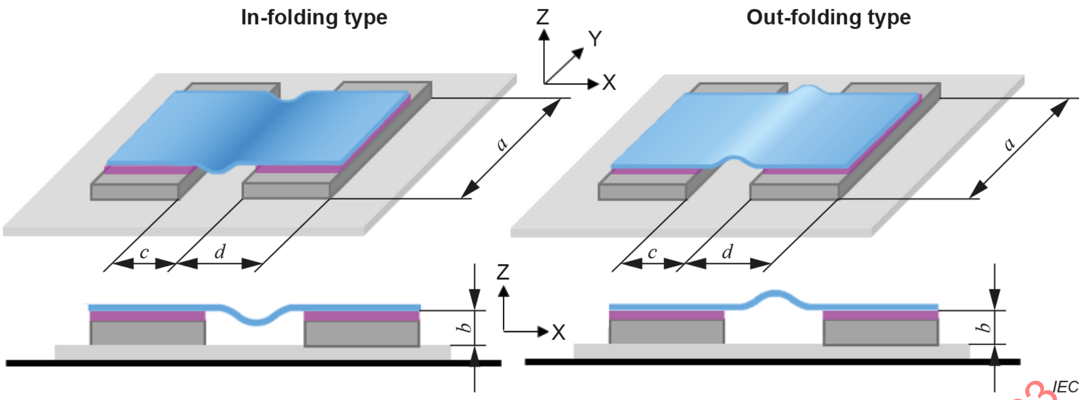


Figure 4 – Step 4: Turning over the base plate with the panel attached

The description of each element is as follows:

'a' length of jig: It should be longer than the width (length of y-axis) of the foldable display panel;

'b' height of jig: It should be high enough that the folding area does not touch the base plate. It can be affected by the folding radius.

'c' unattached area: It should include the folding axis. The minimum value of 'c' should be at least 10 times the foldable panel's bending radius or higher.

NOTE 4 To measure the crease, a folding area is located in the unattached area 'c' and the measurement location will include the unattached area 'c'. The folding area depends on the foldable panel's bending radius. The minimum range of the folding area will be a value obtained by multiplying the bending radius by pi (π). Therefore, to prevent the effects of the fixation of the adhesive on the crease measurement, the unattached area will be at least 10 times the foldable panel's bending radius.

'd' width of jig: It should not intrude the folding area, and it should support the foldable display panel to keep it flat.

The values of 'c' and 'd' shall be determined by the supplier and customer and reported.

The measurement object should be a specimen which consists of the foldable panel fixed on the jig and base plate for reproducibility of the measurement. It is also a similar condition to the foldable panel inserted in the foldable device. However, the attachment method which consists of adhesive fixing while preparing specimen should not affect the measurement. To prevent the forcible pulling of the panel, the process of attaching the panel to the jig with the panel turned over is necessary. This is described in step 2 and step 3. The attachment method shall be reported.

An example of reporting the items for specimen preparation described in 5.3 is shown in Table 1.

Table 1 – Example of specimen preparation condition

Specimen no.	Base plate		Folded storage condition					Foldable panel
	Attachment method	Unattached area ('c') (≥ 10 times the bending radius)	1. Before folding	2. Folded state storage condition			3. Unfolded	Bending radius
			Mechanical test (type/ number)	Temp.	Humidity	Storage time	Delayed time	
No. 1	Adhesive tape	20 mm	Cyclic folding/100	25 °C ± 3 °C	85 %	24 h	15 min	2 R

If a specimen is ready, particles should be removed from the surface before the measurement, using an appropriate cleaning method for the specimens, for example compressed air, wiping with isopropyl alcohol, using an anti-static gun, etc.

5.4 Measurement location

5.4.1 General

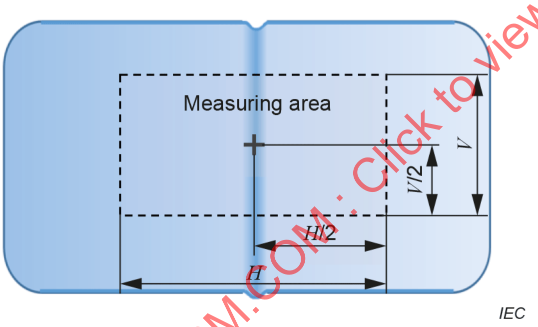
Crease and waviness measurements can be taken at several specified locations on the foldable display panel surface. The height and width of the measuring area shall be determined by the supplier and customer.

5.4.2 Crease

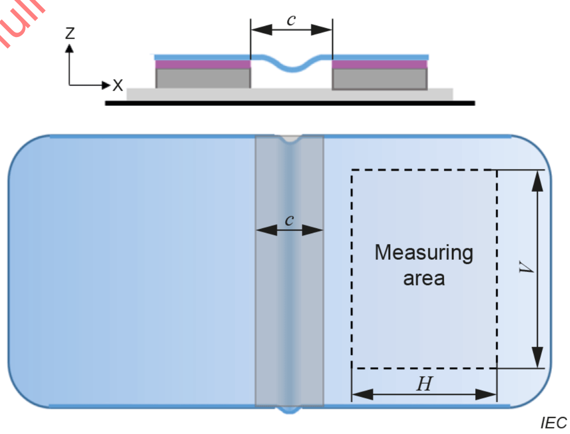
A folding area which is the curved section of the foldable display panel due to folding shall be located in the measuring area. This folding area should be located at the centre of the crease measuring area. Figure 5a) is an example of the crease measuring area in the foldable display panel.

5.4.3 Waviness

The measuring area of waviness shall not include an unattached area ('*c*', having a value of 10 times the foldable panel's bending radius or higher, as described in 5.3). In other words, the measuring area shall be designated from the point at which it is at least 5 times the foldable panel's bending radius away from the folding axis. Figure 5b) is an example of the waviness measuring area in the foldable display panel.



(a) Example of crease measuring area location



(b) Example of waviness measuring area location

Figure 5 – Example of measuring area

6 Measurement methods

6.1 General

In this document, three types of methods are described for implementation:

a) a non-contact method in which a screen is used to measure the surface without contact;

b) a non-contact method using a laser;

c) a contact method in which a stylus contacts the surface for measurement.

The contact method can be used when the non-contact method cannot be performed (e.g., the display surface becomes matte after applying an anti-glare film and the image is not reflected).

However, the contact method is not recommended since this method can damage the foldable display surface.

The non-contact topography (see 6.3) can be adopted to measure both crease and waviness. The non-contact profilometry (see 6.4) and contact profilometry (see 6.5) methods can be adopted to measure crease. These three methods are one of many ways to analyse the surface as described in the introduction. It does not mean that other methods are excluded; these can be selected by decision between the supplier and the customer. Subclauses 6.3.4, 6.4.4 and 6.5.4 focus on how to analyse the measured surface data and express it as crease and waviness of the foldable display. Data comparisons shall be made between the data measured and analysed under the same measurement method, environment, and conditions.

6.2 Purpose

The purpose is to measure the crease and waviness of the specimen which would appear in actual usage. Due to the morphological and geometric changes of crease and waviness, several issues can appear, such as luminance uniformity, viewing angle, and image distortion.

6.3 Non-contact topography

6.3.1 General

To measure crease and waviness the phase measuring deflectometry (PMD) method is used in this document since PMD is the proper method to measure large sizes and it can yield highly accurate data [10]. The principle of PMD is to display fringe patterns on a screen which is located far from the DUT, and to observe the fringe patterns reflected via the surface of the DUT. Any slope variation of the surface of the DUT leads to distortions of the pattern, so the PMD can measure the slope of the surface with high accuracy [11] to [13]. From this measured slope data, the altitude and curvature can be derived by integration and differentiation, respectively[14], [15]. Altitude and curvature are used to represent the crease and waviness, and the principle and data analysis are given in detail in 6.3.2 and 6.3.4.

6.3.2 Test apparatus

Figure 6 shows an example of a measurement system based on PMD. The main devices for PMD include an imaging device (e.g., charge-coupled device (CCD), digital camera), a screen (e.g., TFT-LCD monitor) and a computer. Computer-generated fringe patterns are sequentially displayed on the screen, and the screen shall be flat and sufficiently large so that it can project on the surface of the DUT without distortion. The patterns displayed on the screen in the PMD are typically sinusoidal fringes which are smooth intensity curves, and the phase calculation is not very sensitive to a small amount of out-of-focus effect. The camera captures the reflection of the patterns displayed on a screen through the surface of the DUT [10], [14], [15]. Since PMD is a method of analysing changes between the reference pattern displayed on the screen and the reflected image captured by the CCD, it is important to clearly detect the difference between those two patterns.

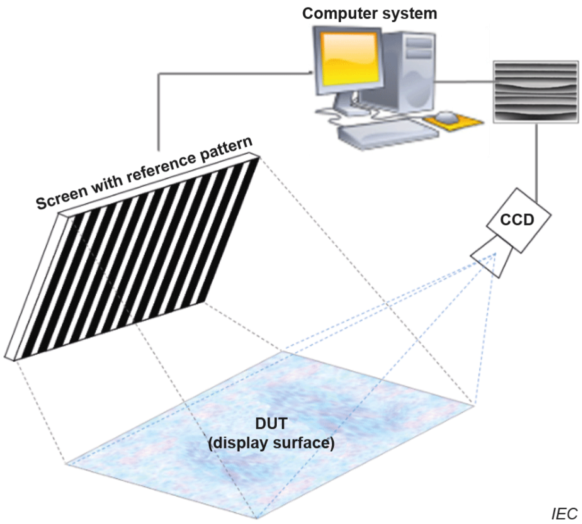


Figure 6 – Example of measurement system

There are many academic papers that have conducted experiments by implementing the PMD method described above [14], [16] to [19].

An example of flowchart for the PMD process is given in Figure 7. After the distortions of the pattern are captured and recorded, the fringe phases shall be retrieved by using the fringe analysis method. The fringe analysis includes fringe demodulation [20] to [25] and phase unwrapping [26] to [28] as shown in Figure 7.

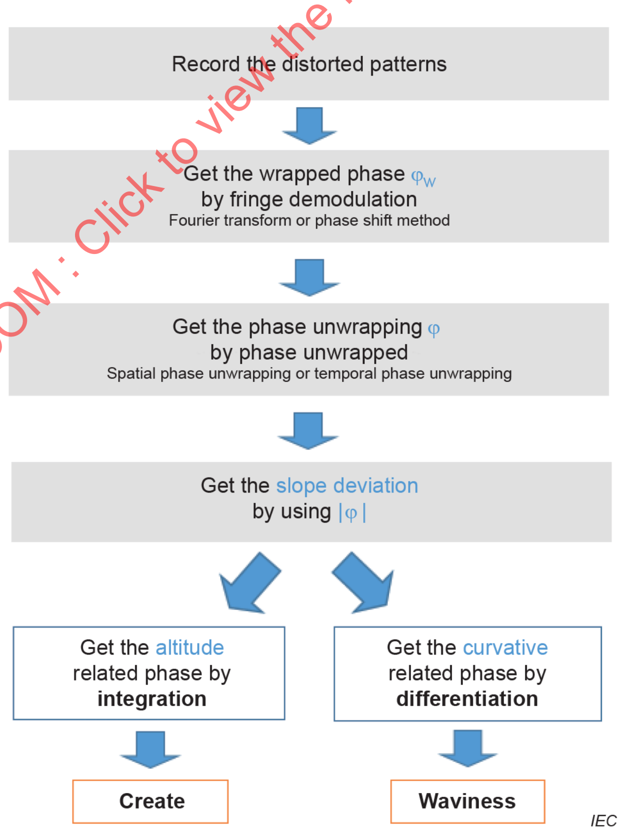


Figure 7 – Analysis flow chart for PMD

Once the absolute phase values are retrieved, their location on the screen can be determined since the period of the fringe pattern on the screen is a known parameter. Using the geometry relations between the surface of the DUT and the camera, the slope of the local area on the surface of the DUT is calculated by tracking the normal direction of the reflected ray at each point on the surface of the DUT.

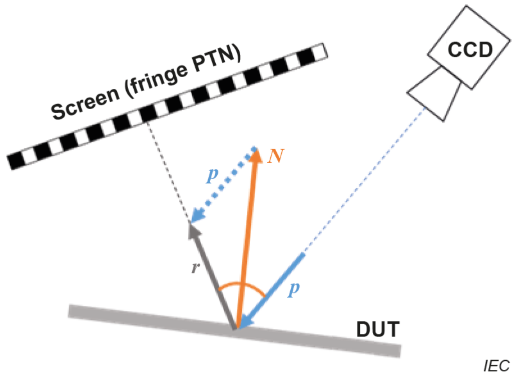


Figure 8 – Surface normal vector N, sight ray of a camera p and reflected ray r

For easier understanding and analysis, the sight ray of a camera is treated as the light source in the PMD although the light is actually illuminated from the screen. Surface normal N can be calculated from the normalized vector of the sight ray of a camera p and reflected ray r. As illustrated in Figure 8, the surface normal vector N can be determined by

$$N = r - p = \begin{pmatrix} N_x \\ N_y \\ N_z \end{pmatrix} \tag{1}$$

where

N_x, N_y, N_z are the x-, y- , and z- components of the surface normal N.

The surface of the DUT's x- and y-slopes (s_x, s_y) are therefore calculated as

$$S_x = -\frac{N_x}{N_z} \tag{2}$$

$$S_y = -\frac{N_y}{N_z} \tag{3}$$

The altitude, which is the height distribution z, is reconstructed from the calculated coordinates (x, y) and slopes (s_x, s_y). This integration process can be express as

$$z = f_{int2}\left(x, y, S_x, S_y\right) \tag{4}$$

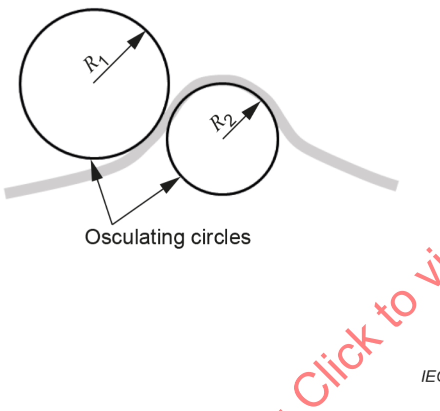
where

$f_{\text{int2}}(\ )$ is an integration function [6].

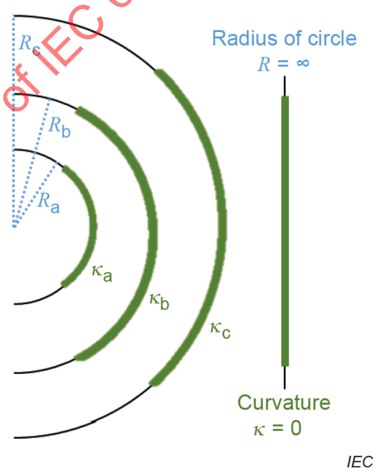
The altitude is calculated by the integration process of Formula (4) from the slope which is calculated by Formula (2) and Formula (3). The difference between the minimum and maximum value of this altitude can measure the crease depth and it can examine the profile of the overall surface of the DUT. The data analysis of crease using this altitude is given in detail in 6.3.4.1.

$$\left(\frac{d^2z}{dx^2}, \frac{d^2z}{dy^2}\right) \tag{5}$$

The curvature is calculated by differentiation using Formula (5) from the slope which is calculated by Formula (2) and Formula (3), and as mentioned in 6.3.1 the curvature can represent the waviness. The meaning of the curvature to be used to indicate waviness is as follows (see Figure 9):



(a) Example of osculating circles



(b) Relation between R and κ

Figure 9 – Osculating circle and curvature

The curvature means the degree to which curves bend. When an osculating circle is defined at the particular point of the surface, the curvature is an inverse number of the osculating circle radius.

$$\kappa = \frac{1}{R} \tag{6}$$

where

κ is the curvature;

R is radius of osculating circle.

The smaller the curvature the larger the radius of the osculating circle, and the surface has a gradual curve. Figure 9b) shows the relation between the osculating circle radius and the curvature. The data analysis of waviness using this curvature of the particular point of the surface is given in detail in 6.3.4.2.

6.3.3 Measurement procedure

The screen, DUT and camera (CCD) are set as described in Figure 8. The screen size, distance between the screen, and surface of the DUT depend on the DUT. The measurement shall be performed as follows:

a) Prepare the required number of specimens in accordance with 5.3.

b) Load the specimen on the test apparatus.

c) Level and align the apparatus and specimen as follows:

   1) the specimen should be aligned so that the vertical direction of the measuring area (which is described in 5.4) and the folding axis of the foldable panel are parallel;

   2) the specimen should be levelled relative to the apparatus' traverse unit. It means the test apparatus is adjusted for tilt relative to the specimen until no significant relative tilt is detected so that the Z value of the X-Y plane of the measuring area is zero.

d) Display the computer-generated sinusoidal fringe patterns on the screen and reflect the fringe patterns on the surface of the DUT.

e) Capture the reflected image by camera (CCD) and record it.

f) Input the information on the phase difference and the geometry relation of the screen, DUT and camera (CCD) location.

g) Calculate the slope of the local area data by the logic described in 6.3.2.

h) Data dropouts or noise that can occur during the measurement should be excluded by the calibration system.

6.3.4 Data analysis and report

6.3.4.1 Crease

Crease shall be analysed as follows:

a) The surface slope of each local point will be obtained as described in 6.3.3. Figure 10 shows an example of this data distribution in the crease measuring area ($H \times V$) which is determined in 5.4, and measured by the CCD having $M \times N$ data resolution.

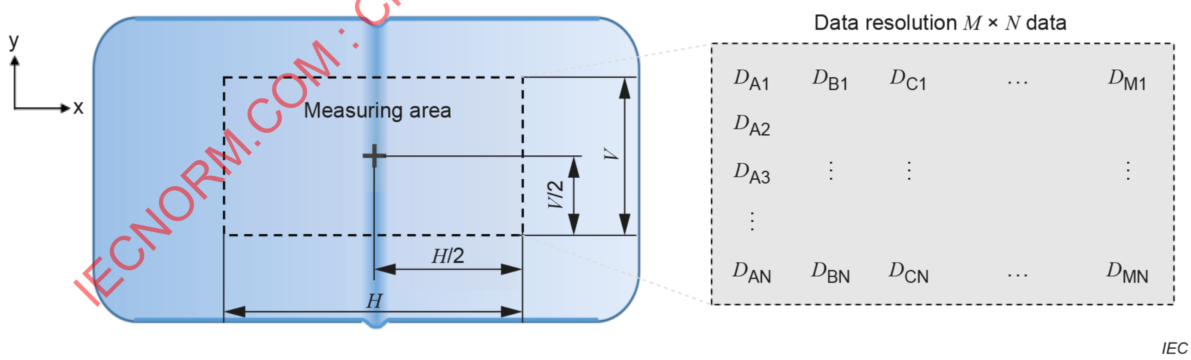


Figure 10 – Example of data distribution in the crease measuring area

b) Using the procedure described in 6.3.2, the $M \times N$ altitude values of each local point shall be calculated using Formula (4) from the $M \times N$ surface slope values of each local point obtained in a).

c) $M \times N$ altitude values can be grouped in the x-axis direction that is vertical with the folding axis as shown in Figure 11; N data bundles are then obtained. One data bundle can be drawn as a graph of the change in the z value according to the x value. Figure 12 shows an example of the N^{th} row profile data.

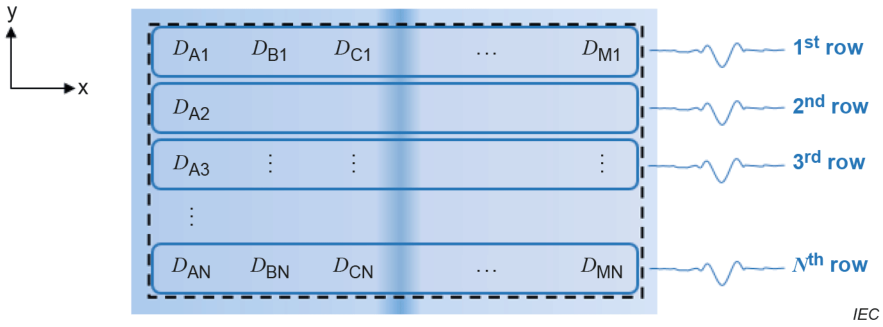


Figure 11 – Example of data grouping on the vertical direction with folding axis

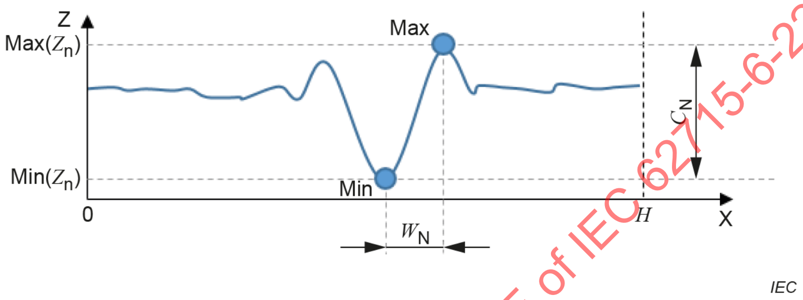


Figure 12 – Example of the N^{th} profile data

d) In the N^{th} row profile graph, the C_N value is defined as the difference between the maximum value of Z and the minimum value of Z. It can be expressed as follows:

$$C_N = \text{Max}(Z_N) - \text{Min}(Z_N) \tag{7}$$

e) $C_1, C_2, \ldots, C_N$ will be obtained by d). The average of these values is defined as the 'crease depth', C_d

$$C_d = \text{AVG}(C_1, C_2, \ldots, C_N) \tag{8}$$

f) In order to obtain the distribution of crease depth data within measuring area, the standard deviation of $C_1, C_2, \ldots, C_N$ values are defined as the 'SD of crease depth', $C_{d,SD}$

$$C_{d,SD} = \text{STDEV}(C_1, C_2, \ldots, C_N) \tag{9}$$

g) In the N^{th} row profile graph, the W_N value is defined as the difference between the X values with the maximum value of Z and the minimum value of Z. It can be expressed as Formula (10); Figure 12 also shows the meaning of W_N. The value multiplied by 2 by the average of $W_1, W_2, \ldots, W_N$ will be defined as the 'crease width', C_w (11).

$$W_N = X_{\max(Z_N)} - X_{\min(Z_N)} \tag{10}$$

$$C_w = 2 \times \text{AVG}(W_1, W_2, \ldots, W_N) \tag{11}$$

h) Report the 'crease data' results with the conditions such as measuring area, and CCD data resolution. Table 2 shows an example of reporting crease data. As described in 5.3, since the conditions of the specimen can affect the result value, the conditions specified in Table 1 shall be reported together with Table 2.

NOTE A gradient of crease can also be calculated by the ratio of the C_N value obtained in Formula (7) to the W_N value obtained in Formula (10), which means C_N over W_N. However, this value cannot represent the crease by itself because it is not enough to express the exact dimension of the crease form. Therefore, if the gradient of crease is used as crease data, it will be reported together with the crease depth and crease width values of Table 2.

Table 2 – Example of crease data report using the PMD method

Measuring area (H × V)	CCD data resolution	Crease data		
		Crease depth	SD of crease depth	Crease width
80 mm × 60 mm	1 000 × 800	-		

6.3.4.2 Waviness

Waviness shall be analysed as follows:

a) The surface slope of each local point will be obtained as described in 6.3.3. Figure 13 shows an example of data distribution in the waviness measuring area (H × V) which is determined in 5.4, and measured by the CCD having M × N data resolution.

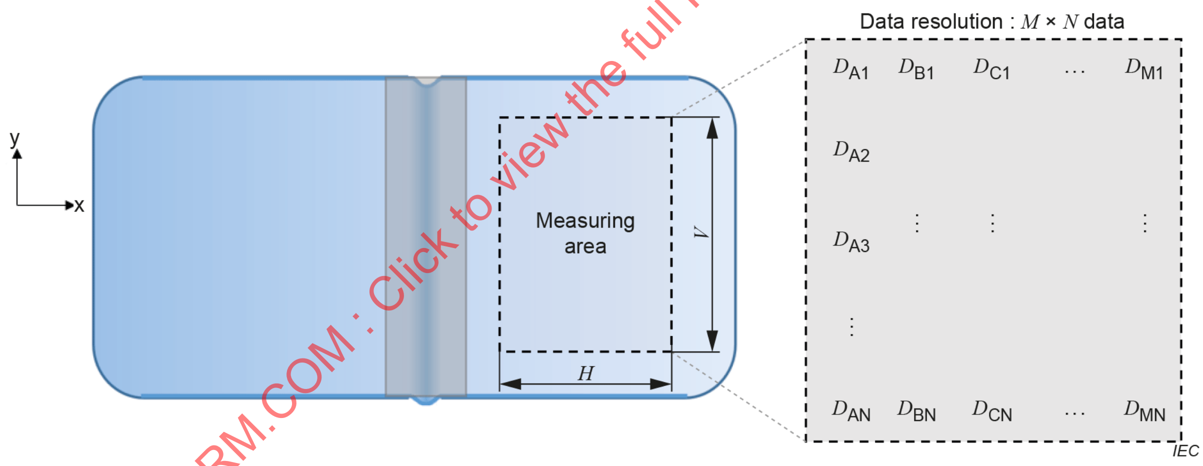


Figure 13 – Example of data distribution in the waviness measuring area

b) Using the method described in 6.3.2, the M × N curvature values (κ, kappa) of each local point shall be calculated by Formula (5) from the M × N surface slope values of each local point obtained in a).

c) Determine the spatial sampling length range to separate the waviness profile from the original profile. By using the profile filter, the curvature value of the desired wavelength range can be calculated. In other words, if the small roughness which is caused by the material component itself or noise is excluded, the waviness which is the surface topography will be obtained by the filtering profile. The concept of the profile filter is shown in Figure 14. The range of the filtering spatial wavelength is determined by the supplier and customer and should be reported. The profile filter and the terms related to it follow those specified in ASME B46.1, ISO 4287, and ISO 16610-21.

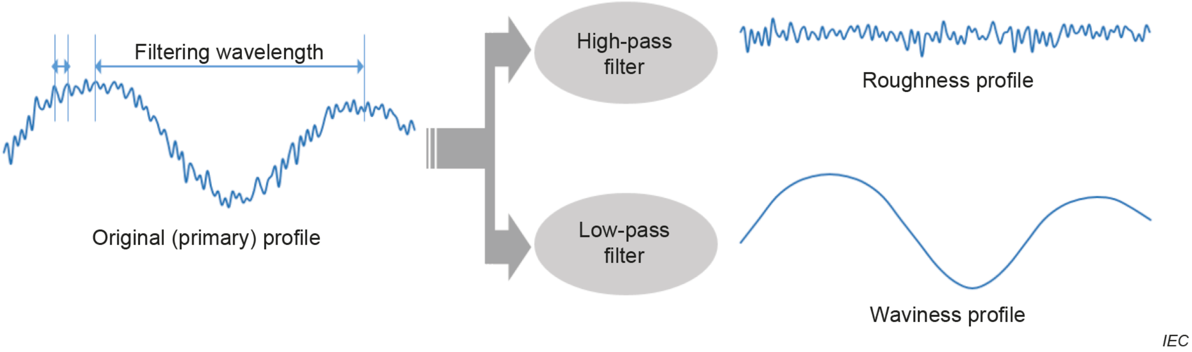


Figure 14 – Concept of filtering profile

d) After applying the profile filter to the data obtained in b), the $M \times N$ curvature values (κ, kappa) of a specific wavelength range will be obtained and can be expressed as κ_{A1}, κ_{A2}, …, κ_{AN}, κ_{B1}, κ_{B2}, …, κ_{BN}, …, κ_{M1}, κ_{M2}, …, κ_{MN}

e) The average of these curvature values is defined as the 'waviness level', W_l.

$$W_l = \mathrm{AVG}(\kappa_{A1}, \kappa_{A2}, \ldots, \kappa_{AN}, \kappa_{B1}, \kappa_{B2}, \ldots, \kappa_{BN}, \ldots, \kappa_{M1}, \kappa_{M2}, \ldots, \kappa_{MN}) \tag{12}$$

f) In order to obtain the distribution of waviness level data within the measuring area, the standard deviation of these curvature values is defined as the 'waviness distribution', $W_{l,SD}$.

$$W_{l,SD} = \mathrm{STDEV}(\kappa_{A1}, \kappa_{A2}, \ldots, \kappa_{AN}, \kappa_{B1}, \kappa_{B2}, \ldots, \kappa_{BN}, \ldots, \kappa_{M1}, \kappa_{M2}, \ldots, \kappa_{MN}) \tag{13}$$

g) Report the 'waviness data' results with the conditions such as measuring area, CCD data resolution, and filtering wavelength range. Table 3 shows an example of reporting waviness data. As described in 5.3, since the conditions of the specimen can affect the result value, the conditions specified in Table 1 shall be reported together with Table 2.

Table 3 – Example of reporting waviness data

Measuring area ($H \times V$)	**CCD data resolution**	**Waviness data**		
		Filtering wavelength range	**Waviness level**	**Waviness distribution**
80 mm × 60 mm	1 000 × 800			

6.4 Non-contact profilometry

6.4.1 General

Laser scanning is another non-contact surface measurement method in which a laser scans a surface to measure its topography. This scanning method is specified in ISO 10360-8 [32]. This method allows for measurement of a multi-layer specimen which can contain polarizers, windows, touch panel, and so on, as individual layers can be selected for measurement.

In general the laser scan technology uses a measurement technique called LIDAR (light detection and ranging) to inject a laser beam into a target object in a measuring instrument and use the direction and distance of the reflected beam from the target to indicate the appearance of the surface shape. The results of the interpretation are recorded as a collection of points distributed on a two-dimensional or three-dimensional coordinate [29].

In 6.4, triangulation laser scanning [30], which is a method for calculating the distance between the laser and CCD by using geometric principles, is described. This method is generally a better way to measure crease than waviness because line scans are performed several times to obtain an overall surface profile. Specifically, the laser scanning principles and method based on the triangulation sensor and the manner in which to quantify the crease with the obtained data will be specified (see Figure 15).

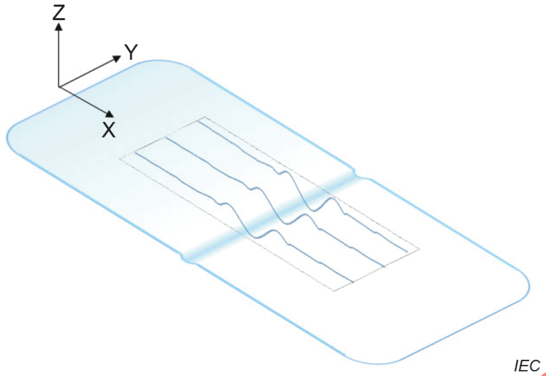


Figure 15 – Schematic of the result of laser scanning

6.4.2 Test apparatus

A laser triangulation sensor consists of a solid-state laser light source and a PSD or CMOS/CCD detector [31]. After the laser beam is projected onto the surface of the specimen to be measured, the reflected beam is detected through the lens. The distance between the laser and the surface is obtained according to the location. If the laser sensor scans through the line while moving in a particular direction after being mounted on the jig, the surface profile on that line will be obtained as data. Figure 16 shows a schematic diagram of the overall laser scanning apparatus.

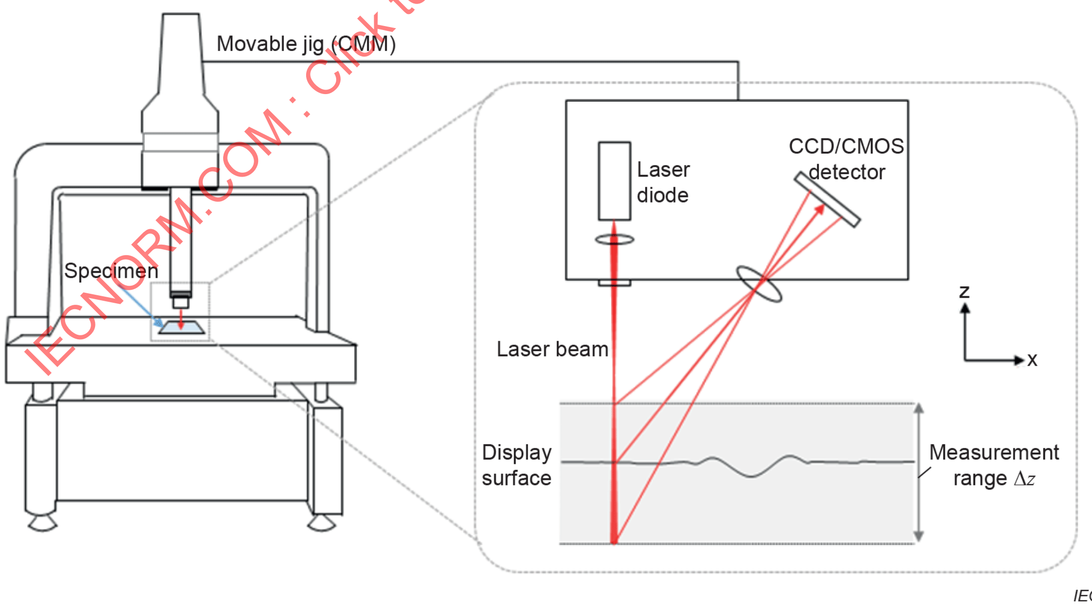


Figure 16 – Schematic diagram of the laser scanning apparatus

As can be seen in Figure 16, the laser sensor is suspended by a large jig that can be moved in the coordinate system. In other words, the laser scan speed is the same as the jig speed. The range of the height (Δz) of the display surface that can be measured is determined according to the specifications of the laser and the detector. If the position of the laser is too far from the display surface, the reflected beam will not be focused into the detector, so the supplier and customer should adjust the z-axis position of the laser so that it functions in the possible range. Auto focusing can be possible depending on the equipment.

The range of the surface height which the CCD can detect becomes Δz. In that range, the laser records the relative height of the surface while line scanning in the direction specified by the supplier and customer on the X-Y plane.

Since the surface profile data interval is determined according to the speed of the laser moves and the CCD sampling period, all of these conditions have to be determined and reported by the supplier and customer. For example, if the scan speed is set too fast in the condition of a low CCD sampling period, the accuracy of the profile will be lowered because there can be a point where the laser sensor passes without being able to detect. Therefore, it is necessary to specify the scan speed considering the sampling period of the CCD.

The size of the beam depends on the resolution of the laser. The smaller the beam size, the higher the resolution to detect the surface. The beam size and resolution shall be determined and reported by the supplier and customer according to the required resolution. In addition, the laser beam shall have an output intensity and a wavelength within the limit that does not cause damage on the display surface. In general, most laser sensors use a visible light (for example red or green wavelength) to be able to see which point of the specimen is measured. An example of reporting the contents described in 6.4.2 is shown in Table 4.

Table 4 – Example of laser scanning apparatus condition

Laser beam size	Laser beam wavelength	Sampling period of CCD	Laser resolution
1 mm × 1 mm	650 nm	1 ms	8 µm

6.4.3 Measurement procedure

The measurement shall be performed as follows:

a) The specimen which is prepared in accordance with 5.3 shall be mounted on the base plate of the CMM apparatus as shown in Figure 16. When the specimen is placed on the X-Y plane of the base plate where the apparatus scans, the folding axis of the panel should be parallel to the x-axis or y-axis. The specimen should be levelled relative to the apparatus traverse unit. This means that the test apparatus is adjusted for tilt relative to the specimen until no significant relative tilt is detected, so that the z value of the X-Y plane of the measuring area will be zero. The base plate of the CMM apparatus where the specimen is to be mounted should have no vibration and be flat.

b) Specify the (x, y) coordinates of position 1 and position 2 of the measuring area which is determined in 5.4. Position 1 is located in the top left corner and position 2 is located in the bottom right corner of the measuring area. These positions are the start point and the end point of the measurement, respectively, and the area of measurement becomes $|x_2 - x_1|$ x $|y_2 - y_1|$. The example of the specified position 1 and position 2 in the crease measuring area is shown in Figure 17.

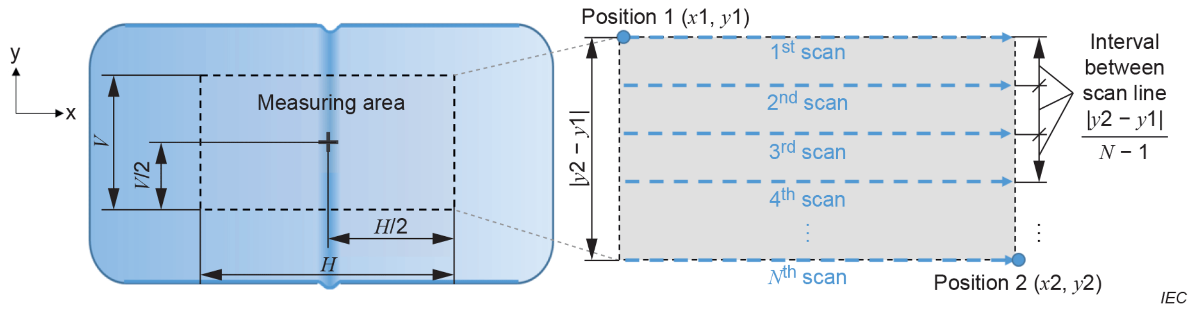


Figure 17 – Example of position 1 and position 2 in the crease measuring area

c) The CMM apparatus should be perpendicular to the direction of the traverse. Adjust the CMM apparatus in the z-axis direction to position the laser sensor in a measurable range. Auto focusing can be possible depending on the equipment.

d) The scan direction and the number of scans (N) shall be determined by the supplier and customer. Since the scan direction should be perpendicular to the folding axis, it depends on the mounting direction of the specimen in 6.4.3 a). The number of scans (N) should be bigger than 2.

e) The scan starts from position 1, and the line scan is performed in a specific direction which is determined in 6.4.3 d). The (x, y, z) is recorded as the data. (x, y) means the coordinate location in the measuring area and z means the height of the specimen surface. The scan ends in position 2.

f) As described in 6.3.3 h), noise data should be excluded.

6.4.4 Data analysis and report

The measured data shall be analysed as follows:

a) Figure 17 shows an example of the location and interval between scan lines when scanning N times in the +x-axis direction in the measuring area. Since the line scan is performed N times at equal intervals within the measuring area designated by position 1 and position 2, the interval between the scan lines will be $|y_2 - y_1| / (N - 1)$.

b) By performing N scans, N data bundles consisting of (x, y, z) can be obtained. As explained in 6.4.1, the interval of each (x, y, z) data will be determined according to the sampling period of the CCD and the speed of the CMM apparatus.

c) As described in 6.3.4.1 c) if scanning is performed in the +x-axis direction as shown in Figure 11 , one data bundle can be drawn as a graph of the change in the z value according to the x value. Figure 12 shows an example of the N^{th} scanned profile data.

d) As described in 6.3.4.1 d), the C_N value shall be calculated by using Formula (7).

e) As described in 6.3.4.1 e), C_1, C_2, … , C_N will be obtained and 'crease depth' shall be calculated by using Formula (8).

f) As described in 6.3.4.1 f), the standard deviation of these C_1, C_2, … , C_N values shall be calculated by using Formula (9).

g) As described in 6.3.4.1 g), the W_N value and 'crease width' shall be calculated by using Formula (10) and Formula (11).

h) Report the 'crease data' results with all of the conditions such as number of scans (N), scan speed, and measuring area. Table 5 shows an example of reporting crease data. As described in 5.3, since the conditions of the specimen can affect the result value, the conditions specified in Table 1 shall be reported together with Table 5.